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CHRONOLOGY OF RÖNTGEN'S LIFE*

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72 45/27

1845—March 27—Born at 287 Poststrasse in Lennep, Rhine Province, Germany.

1848—May—Röntgen family moved to Apeldoorn, Holland.

1862—Dec. 27—Entered Utrecht Technical School, Holland

1865—Jan. 18—Entered University of Utrecht to audit courses as a student of mechanical engineering.

Nov. 16—Moved to Zürich, Switzerland as a student of mechanical engineering at the federal Polytechnical School.

1866—Met Anna Bertha Ludwig, who was born on April 22, 1839, in Schwamendingen, Switzerland.

1868—Aug. 6—Graduated as mechanical engineer from the Polytechnical School of Zürich, Switzerland.

1869—June 22—Received Ph.D. degree from the University of Zürich and became assistant to August Kundt, professor of physics.

1870—In the capacity of assistant, Röntgen followed Kundt to the Julius-Maximilian University at Würzburg.

1872—Jan. 19.—Married Anna Bertha Ludwig of Zürich in Apeldoorn, Holland.

Followed Kundt to the University of Strassburg as his assistant.

1873—Oct. 3—Röntgen's parents moved from Apeldoorn to Strassburg to live near their children.

1874—March 13—Became *Privat-dozent* in physics at the University of Strassburg.

1875—April 1—Became professor of physics and mathematics at the Agricultural Academy at Hohenheim in Württemberg.

1876—Oct. 1—Returned to the University of Strassburg as associate professor of theoretical physics.

1879—April 1—Became professor of physics at the Hessian Ludwigs-University in Giessen.

1884—June 21—Röntgen's father died at Giessen.

1886—Declined offer of chair of physics at the Friedrich-Schiller University of Jena.

1887—The Röntgens took Josephine Bertha, Mrs. Röntgen's six year old niece, into their home and adopted her when she was twenty-one.

1888—Declined offer of chair of physics at the University of Utrecht.

Aug. 8—Röntgen's mother died at Bad Nauheim.

Oct. 1—Became professor of physics at the Julius-Maximilian University in Würzburg.

1894—May—August Kundt died at his summer home near Lübeck.

June—Röntgen acquired an improved Lenard cathode-ray tube from Mül-

* From: Glasser, Otto. Dr. W. C. Röntgen. Charles C Thomas, Springfield, Illinois, 1945.

ler-Unkel in Braunschweig for experimental studies.
Became rector of the University of Würzburg.

1895—Feb.—Declined offer of chair of physics at the Albert-Ludwigs University in Freiburg i. Br.

Nov. 8—Röntgen discovered the first effects due to *A new kind of rays*.

Dec. 28—Submitted the manuscript of a paper *On a new kind of rays, a preliminary communication* to the secretary of the Würzburg Physical-Medical Society for publication in its *Sitzungsberichte*.

1896—Jan. 1—Sent reprints of his first communication and copies of his x-ray pictures to his colleagues Exner, Kohlrausch, Lummer, Poincaré, Schuster, Voller, Warburg, and Zehnder.

Jan. 4—Röntgen's first x-ray pictures were exhibited at the Physical Institute of Berlin University on the occasion of the fiftieth anniversary celebration of the Berlin Physical Society.

Jan. 5—First newspaper story of the discovery of x-rays appeared in the Vienna *Presse*.

Jan. 6—News of the discovery was cabled all over the world.

Jan. 13—Röntgen demonstrated the x-rays before Kaiser Wilhelm II and Kaiserin Victoria at the Berlin castle; he was decorated with the Prussian Order of the Crown, II class.

Jan. 23—Lectured on his discovery of x-rays before the Physical-Medical Society at the Physical Institute of the University of Würzburg.

Jan. 30—Declined to lecture before the German Reichstag and several scientific societies.

March 3—Honorary degree of Doctor of Medicine of the University of Würzburg.

March 9—Submitted the manuscript of his second communication, *On a new kind of rays, continued*, to the secretary of the Würzburg Physical-Medical Society.

March 10—Left for Sorrento to escape the flood of honors and invitations.

April 16—Honorary citizen, Lennep, Röntgen's birthplace.

April 20—Royal order of merit of the Bavarian Crown. This order carried with it personal nobility. Röntgen accepted the decoration but refused to accept nobility.

May—Corresponding member, Prussian Academy of Sciences, Berlin.

Nov.—Corresponding member, Bavarian Academy of Sciences, Munich.

Nov. 30—Rumford gold medal, Royal Society, London.
Baumgaertner prize, Vienna Academy.
Honorary member, Naturforscher-Gesellschaft, Freiburg i. Br.
Honorary member, Société Scientifique Antonio, Alz. Mexico.
Honorary member, Physical Society, Frankfort, o. M.
Honorary member, Chester Society of Natural Sciences.
Corresponding member, Société Nationale des Sciences et Mathématiques, Cherbourg.
Corresponding member, Wissenschaftliche Gesellschaft, Göttingen.

1897—March 10—Submitted his third communication, *Further observations on properties of x-rays*, to the Prussian Academy of Science, Berlin for publication in its *Sitzungsberichte*.
Elliot-Cresson medal, Franklin Institute, Philadelphia.
Prize Lacaze, Academie des Sciences, Paris.
Mattencei medal, Rome.
Honorary member, Swiss Naturforscher Gesellschaft.
Honorary member, Physical-Medical Society, Erlangen.
Honorary member, Röntgen Society, London.
Honorary member, Société des Médecines Russes, Petersburg.
Honorary member, Sociéte Impériale de Medicine, Constantinople.
Honorary member, Society of Former Students of Federal Polytechnical School, Zürich.
Corresponding member, Reale Accademia di Geographici, Florence.
Member, American Philosophical Society, Philadelphia.

1898—Prize, Otto-Wahlbruch-Stiftung, Hamburg.
Honorary member, New York Medical Society.
Corresponding member and bronze plaque, Reale Accademia dei Lincei, Rome.
Corresponding member, Reale Instituto Veneto di Scienze.
Nonresident member of the Société Hollandaise des Sciences, Harlem.

1899—Received offer of chair of physics at the University of Leipzig but declined.
Received the title of *Royal Geheimrat* from the Bavarian Government.
Diploma, University of Zürich.
Corresponding member, Cataafsch Genootschap, Rotterdam.
Nonresident member, Royal Academy of Sciences, Stockholm.

1900—April 1—Became professor of physics and director of the Physical Institute at the Ludwig-Maximilians University in Munich.
Grosskomturkreuz of the royal order of merit of the Bavarian Crown.
Order of merit of Saint Michael, I Class.
Silver medal of Prince Regent Luitpold.
Komtur of the order of the Italian Crown.
Member of the Maximilian order for sciences with decoration.
Barnard medal, Columbia University, New York.
Honorary member, German Academy for Phys. Diet. Therapy, Hamburg.
Honorary member, Society of Physicians, Munich.
Nonresident member, Academy of Medicine, Paris.
Member, Academy of Sciences, Munich.

1901—Nobel Prize in Physics, Stockholm.
Honorary member, Physical Society, Stockholm.

1902—Received invitation of Carnegie Institute in Washington to use its laboratory for special work but did not accept.
Honorary member, Institute de Coimbra.

1903—Honorary member, Philosophical Society, Cambridge.
Honorary member, Berlin Röntgen Society.
Corresponding member, Reale Accademia dei Science, Turin.

1904—Declined offer of presidency of Physikalisch-Technische Reichsanstalt in Berlin-Charlottenburg.
Honorary member, Society of Physicians, Vienna.
Röntgenstrasse, Cologne.

1905—March 27—Address of German physicists, Boltzmann, Braun, Drude, Ebert, Graetz, Kohlrausch, Lorentz, Planck, Riecke, Warburg, Wien, Wiener, Zehnder on the occasion of the tenth anniversary of the discovery of the roentgen rays, which was also Röntgen's sixtieth birthday; plaque at Physical Institute of University of Würzburg.
Honorary member, Society for the Encouragement of Arts, etc., London.
Honorary member, Medico-Chirurgical Society, Edinburgh.
Honorary member, German Röntgen Society.

1906—Folder, board of trustees, Deutsches Museum, Munich.
Honorary member, Royal Institution of Great Britain.

1907—Nonresident member, Societa Italiana delle Scienze, Rome.
Member, Royal Academy of Sciences, Amsterdam.

1908—Honorary member, Society of Physicians, Stockholm.
Honorary member, German Medical Society, New York.
Title of Excellency bestowed upon Röntgen by the Prince Regent of Bavaria.

1909—Röntgenstrasse, Würzburg.
Honorary citizen, Weilheim.

1910—Honorary member, German Society of Neurologists.
Honorary member, Berlin Medical Society.

1911—Röntgenstrasse, Halle.
Honorary member, Society of Physicians, Smolensk.
Order pour le Mérite for Science and Art.

1912—Declined offer of professorship at Prussian Academy of Sciences, Berlin.
Russian diploma, Odessa.
Planned to visit relatives in America.
Address, life membership Deutsches Museum, Munich.

1913—Honorary member, German Surgical Society.
Honorary member, Swiss Röntgen Society.

1914—Honorary member, New York Röntgen Society.

1915—March 27—Röntgen spent his seventieth birthday quietly with his best friend, Boveri, who was seriously ill in Oberstdorf, Bavaria; on the next day he had an audience with the King of Bavaria in Munich.
Addresses and honors on the occasion of Röntgen's seventieth birthday:
Würzburg Medical Faculty.
Röntgen Foundation.
University of Giessen.
Philosophical Faculty, University of Würzburg.
Physikalisch-Technische Reichsanstalt.
University of Strassburg.
Annalen der Physik.
Röntgenstrasse, Munich.
Iron Cross, II Class.

1918—Honorary degree of doctor of engineering, Technical High School, Munich.

1919—June 22—Fiftieth anniversary of Röntgen's doctorate in philosophy. He received the following honors:
Fiftieth doctorate diploma, University of Zürich.
Address of Prussian Academy of Sciences, Berlin.
Helmholtz medal in bronze.
Helmholtz medal in gold.

1920—Honorary member, German Physical Society.
Röntgen retired from the University of Munich and became professor emeritus.

March 27—Röntgen's seventy-fifth birthday. He received the following honors:
Honorary degree of Doctor of Natural Sciences, Johann Wolfgang Goethe University, Frankfort o. M.
Honorary member, Bonn Röntgen Society.
Honorary member, Frankfort Röntgen Society.
Honorary member, Society for Natur and Heilkunde, Dresden.
Commemorative tablet placed on the house of Röntgen's birth and an address by the mayor of the city of Lennep.
Nonresident member, Prussian Academy of Sciences, Berlin.
Nonresident honorary member, Vienna Academy of Sciences.
Member, Strassburg Scientific Society, Heidelberg.
Röntgenstrasse, Lennep.
Röntgenstrasse, Weilheim.
Honorary citizen, Würzburg.

1921—Honorary member, Society and Friends of the Friedrich-Wilhelm University of Bonn.
Honorary member, Nordisk Foereningf. med. Radiologi.
Honorary academician, University of Bonn.
Corresponding member, Phys. Oekonom Society.

1922—Commemorative tablet placed on the house Röntgen lived in during his Zürich college years, Swiss Röntgen Society.

1923—Feb. 10—Röntgen died at Munich.
Nov. 10—Röntgen's ashes were put to rest in the family grave at Giessen.

1928—July 27—Röntgen bust, sculptured by Georgii, unveiled at the University of Munich.
Dec. 9—Röntgen Memorial Room opened at the Physical Institute, University of Würzburg.

1930—Nov. 30—Röntgen monument unveiled in Lennep.
Röntgen-Realgymnasium, Lennep.

1932—June 18—Röntgen Museum opened in Lennep.

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SCIENTIFIC FOREFATHERS OF RÖNTGEN

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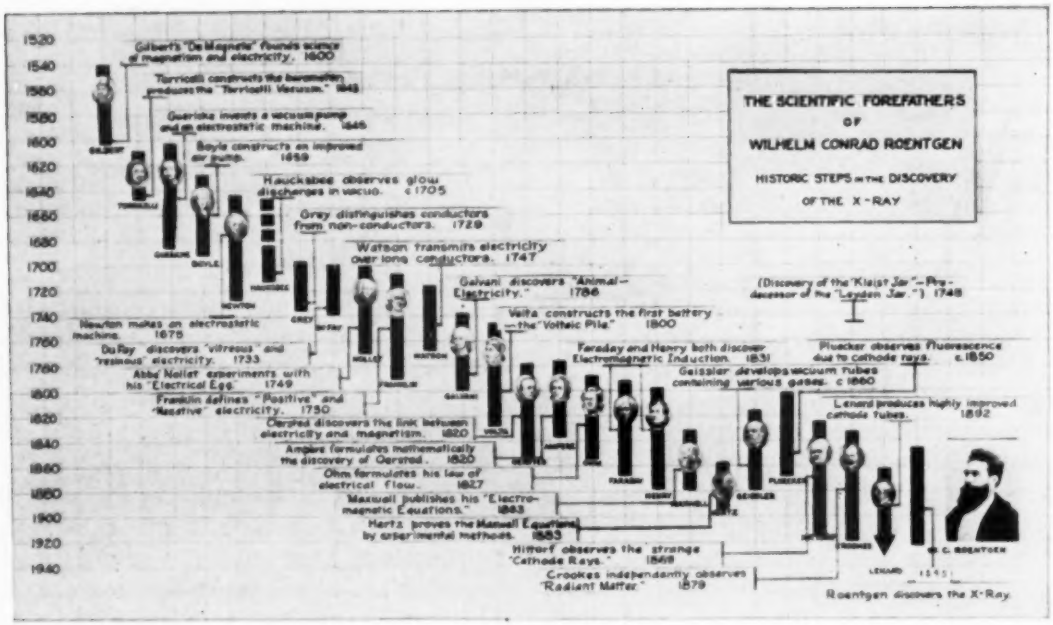
JOSEPH PRIESTLEY, the British scientist who sought refuge in the United States in 1794, was the originator of an interesting Chart of Biography. According to his own description[1] this chart "represents the Interval of Time between the Year 1200 before Christ, and 1800 after Christ, divided, by an equal Scale, into Centuries. It contains about two thousand Names of Persons the most distinguished in the Annals of Fame; and the Length of their Lives is represented in it by Lines drawn in proportion to their real Duration, and placed so as to show, by Inspection, how long any number of Persons were contemporary, and how long one Life began before, or extended beyond another, with every other Circumstance which depends upon the Length of Lives, and the relation they bear, both to one another, and to Universal Time; Certainty being always represented by full lines, and Uncertainty by Dots, or broken Lines."

Several years ago, in collaboration with Leopold Rovner, I applied Priestley's ingenious method to a historical evaluation of scientific men whose work led up to the discovery of the roentgen rays (see figure). The chart was first shown in the scientific exhibit at the eighteenth annual meeting of the Radiological Society of North America in Atlantic City in 1932. A more comprehensive treatise was published under the title "Genealogy of the Roentgen Rays."[2]

The ordinate of the chart represents a time interval from 1520 to 1940, subdivided into intervals of twenty years; the abscissae are evenly spaced intervals for twenty-six selected scientists. The time of birth, life span, and time of death of each is indicated by a vertical black line placed chronologically upon the time scale indicated on the ordinate. Two life spans are incomplete: that of Hauksbee, whose year of birth is unknown, and that of Lenard, who was alive at the time of the completion of the chart. It is immediately evident that some life spans are very short, such as those of Torricelli or Hertz, while others are very long, such as those of Guericke, Newton, Franklin, Volta, Henry, Hittorf, and Crookes.

The chart offers ample evidence of the usefulness of this type of presentation. A conventional presentation of the data contained in the figure probably demonstrates this fact better by comparison than any further description.

1540–1603 Gilbert
1603 Gilbert's "De Magnete" founds science of magnetism and electricity
1608–1647 Torricelli
1643 Torricelli constructs the barometer, produces the "Torricellian vacuum"
1602–1686 Guericke
1646 Guericke invents a vacuum pump and an electrostatic machine
1627–1691 Boyle
1659 Boyle constructs an improved air pump
1642–1727 Newton
1675 Newton makes an electrostatic machine
? –1713(?)Hauksbee
1705 Hauksbee observes glow discharges in vacuo
1696–1736 Grey
1729 Grey distinguishes conductors from non-conductors
1698–1739 Du Fay
1733 Du Fay discovers vitreous and resinous electricity
1700–1770 Nollet
1749 Abbé Nollet experiments with his "electric egg"
1706–1790 Franklin
1750 Franklin defines positive and negative electricity


THE SCIENTIFIC FOREFATHERS
OF
WILHELM CONRAD ROENTGEN
HISTORIC STEPS IN THE DISCOVERY
OF THE X-RAY
1520
1540
1560
1580
1600
1620
1640
1660
1680
1700
1720
1740
1760
1780
1800
1820
1840
1860
1880
1900
1920
1940
Gilbert's "De Magnete" founds science of magnetism and electricity. 1600
Torricelli constructs the barometer, produces the "Torricelli Vacuum." 1643
Guericke invents a vacuum pump and an electrostatic machine. 1646
Boyle constructs an improved air pump. 1659
Hauksbee observes glow discharges in vacuo. c1705
Gray distinguishes conductors from non-conductors. 1729
Watson transmits electricity over long conductors. 1747
Galvani discovers "Animal-Electricity." 1786
Volta constructs the first battery —the "Voltaic Pile." 1800
(Discovery of the "Kleist Jar"—Predecessor of the "Leyden Jar.") 1748
Newton makes an electrostatic machine. 1675
Du Fay discovers "vitreous" and "resinous" electricity. 1733
Abbé Nollet experiments with his "Electrical Egg." 1749
Franklin defines "Positive" and "Negative" electricity. 1750
Oersted discovers the link between electricity and magnetism. 1820
Ampère formulates mathematically the discovery of Oersted. 1820
Ohm formulates his law of electrical flow. 1827
Maxwell publishes his "Electromagnetic Equations." 1873
Hertz proves the Maxwell Equations by experimental methods. 1883
Faraday and Henry both discover Electromagnetic Induction. 1831
Geissler develops vacuum tubes containing various gases. c 1860
Plücker observes fluorescence due to cathode rays. c.1850
Lenard produces highly improved cathode tubes. 1892
Hittorf observes the strange "Cathode Rays." 1869
Crookes independently observes "Radiant Matter." 1879
W. C. ROENTGEN
LENARD
1845
Roentgen discovers the X-Ray

The original multicolored chart measures $2\frac{1}{4}$ by $3\frac{1}{2}$ feet. The name of each scientist is inserted immediately beneath his life line; his portrait, if available, is superimposed upon the life line. The most important contribution of each scientist is dated and points to the year when it was made. Since the chart was compiled more reliable data have been found which have been incorporated in the tabulation.

1715–1787 Watson
1747 Watson transmits electricity over long conductors
1737–1798 Galvani
1786 Galvani discovers "animal electricity"
1745–1827 Volta
1800 Volta constructs the first battery, the "Voltaic pile"
1777–1851 Örsted
1820 Örsted discovers the link between electricity and magnetism
1775–1836 Ampère
1820 Ampère formulates mathematically the discovery of Örsted
1787–1854 Ohm
1827 Ohm formulates his law of electrical flow
1791–1867 Faraday
1831 Faraday and Henry both discover electromagnetic induction
1797–1878 Henry (see Faraday)
1831–1879 Maxwell
1873 Maxwell publishes his "electromagnetic equations"
1857–1894 Hertz
1887 Hertz proves the Maxwell equations by experimental methods.
1814–1879 Geissler
1860 Geissler develops vacuum tubes containing various gases
1801–1868 Plücker
1850 Plücker observes fluorescence due to cathode rays
1824–1914 Hittorf
1869 Hittorf observes the strange cathode rays
1832–1919 Crookes
1879 Crookes independently observes radiant matter
1862– Lenard
1892 Lenard produces highly improved cathode tubes
1845–1923 Röntgen
1895 Röntgen discovers the x-ray

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2. GLASSER, OTTO. Genealogy of the roentgen rays. AM. J. ROENTGENOL. & RAD. THERAPY, 1933, *30*, 180–200; 349–367.

POST-WAR VISIT TO RÖNTGEN'S LABORATORY

By LIEUTENANT COLONEL LEWIS E. ETTER
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ONE of my first thoughts on being assigned to duty with the Army of Occupation in Germany was to wonder about the present condition of Würzburg and particularly of Röntgen's Laboratory in the Physical Institute of the University of Würzburg. After looking at endless scenes of demolition and devastation of the cities in northwestern Germany, I was fearful of what might have befallen the scene of Röntgen's classical experiments. From the days of my earliest association with radiology, I was attracted to the character of the great physicist, and having read his notable biography by Glasser,[1] my desire to see the spot where he worked had been greatly enhanced. So, in September of this year when the opportunity was afforded, all personnel of our department* set out for that town in Bavaria, made famous by the great discovery of just fifty years ago.†

No doubt the same question as to the present condition of Röntgen's Laboratory has occurred to many radiologists and it is to answer them that this account is given.

As we arrived in the environs of Würzburg our apprehension mounted, for even in the suburbs bomb destruction was seen everywhere. As we journeyed on into the city we met with rubble-strewn streets and, it being a warm day, with the stench of death from those buried in the ruins. We were directed to the University, and as we rode on our anxiety mounted. What was pointed out to us as the University was broken walls, stark chimneys and empty windows. But among all the ruins miraculously stood the Physical Institute, intact, except for some loose slate, plaster and broken windows (Fig. 1). A high explosive aerial bomb apparently directed at the main railroad station early in March,

FIG. 1*a*. View of one end of the Physical Institute of the University of Würzburg showing the plaque commemorating Röntgen's discovery. NA means "not ausgang" or way out from the air raid shelter in the basement.

[1] Glasser, Otto. Wilhelm Conrad Röntgen und die Geschichte der Röntgenstrahlen. Julius Springer, Berlin, 1931. Also, Wilhelm Conrad Röntgen and the Early History of the Roentgen Rays. Charles C Thomas, Springfield, Illinois, 1934.

* X-Ray Department, 115th General Hospital, United States Army.

† A later visit was made to Remscheid-Lennep, the town between Düsseldorf and Cologne where Röntgen was born one hundred years ago (on March 27, 1945). Even though Lennep is situated in the western industrial heart of Germany (the Ruhr) which was subjected to most severe bombing, the town was spared almost completely. The house where Röntgen was born and the other one containing the Röntgen museum sustained not the slightest damage. These buildings look exactly today as pictured in Glasser's biography although the back portion of the museum has been considerably enlarged. Here there is a remarkable collection of Röntgeniana and a display of roentgen-ray equipment arranged chronologically from the first tubes used to the latest perfected machines, including a working model of the roentgen cinematograph designed by Prof. Dr. Janker of Bonn. To date there have been some 20,000 visitors from all over the world to the museum, which is well worth a long trip to see.

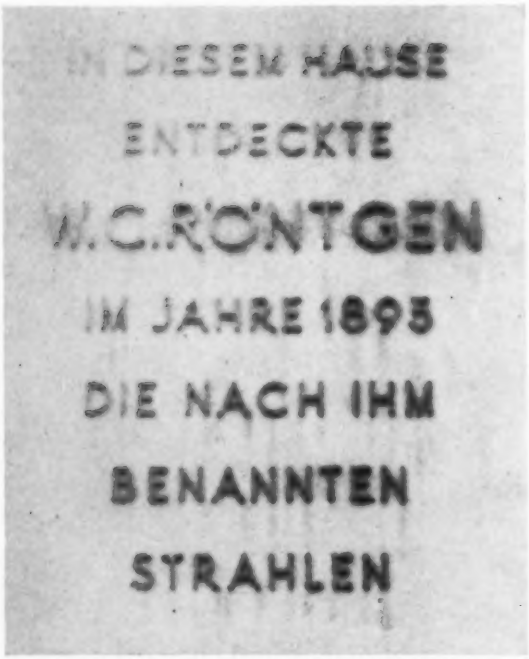

Fig. 1*b*. Close-up of plaque translated to read: "In this house in the year 1895 W. C. Röntgen discovered the rays which were named after him."

1945, landed in the park across from the Institute and blew out all the windows and doors. During the main attack on the city in the night of March 16, some 240,000 incendiary bombs were dropped during twenty minutes and, within three hours, nearly all of the city was burned. About two hundred high explosive bombs followed and one completely wrecked the Anatomy Institute, two buildings removed, with a blast that loosened much of the slate on the Physical Institute. Only three incendiary bombs touched this building and each was extinguished before much damage resulted. Unharmed, on the side of the building, was the plaque translated to read, "In this house in the year 1895

Fig. 2. View in lecture room of the Physical Institute used during the last school session for instruction of students in the University of Würzburg. (Thanks are due T/4 Paul Walkup for the use of this photograph.)

W. C. Röntgen discovered the rays which were named after him."

At the door we were welcomed by the present Professor of Physics* and his assistants who very kindly showed us all through the building. They too could hardly believe the providential sparing of their Institute when all else—to use the expressive German word—was kaputt. They were engaged in making what minor repairs they could, where glass and other materials were available, and in returning to their proper places the historical collection and other things which had been placed in the basement for safe keeping. A remarkable fact was that Röntgen's gun was not picked up as a souvenir by soldiers of our conquering armies since it stood in a corner of the room in plain view when the soldiers went through. All that protected it was a sign attached to it in English written by the Germans saying, "This is the gun which Röntgen first photographed with his rays. If taken, please take it with care and precaution as it is a museum piece."

FIG. 3*a*. View of Röntgen's desk and mementoes: Roentgenogram of von Kolliker's hand and that of Röntgen's wife; Cambridge Society medal; Nobel Prize diploma; gun stock and barrel of gun; roentgenogram of barrel of gun; Crookes, Lenard, Hittorf and "absolute vacuum" tubes; death mask of Röntgen's hands; photographs of Röntgen and of his mother and father.

The rooms where Röntgen had worked were still in use and were said to be in much the same condition as he left them. The lecture hall where he delivered his memorable report on "Über eine neue Art von Strahlen"† on January 23, 1896, before the Physical and Medical Association of Würzburg, was still being used for instruction of students of physics at the University. A view of the blackboard and demonstra-

* Prof. Dr. Friedrich Harms, Director of the Physical Institute; Prof. Dr. Heinrich Ott, Associate Professor of Physics; Dozent Dr. Karl Gailer, Assistant Professor of Physics.

† "About a new kind of rays."

tion table is shown in Figure 2. In his private office are preserved his library containing classics on physics by such men as Helmholz, Thomson, Volta, and Faraday, among many others; his honorary degrees and orders from universities and governments the world over, and the first Nobel Prize awarded in Physics (1901) shown in Figures 3*a* and 3*b*. This, and several other articles of interest, were grouped together on his desk for photographing and will be familiar to many. The roentgenogram of his double-barreled gun, showing defects in the metal, is curious as the example of the very first "industrial film." The moulage of his hands made after death is eloquent in itself. In another case were standing the tubes with which he had experimented, Hittorf's, Lenard's, Crookes', the "absolute vacuum" tube and the piece of cardboard coated with barium platinocyanide which he had seen light up and fluoresce when brought into proximity with a covered and activated cathode-ray tube. The box of weights with a film showing their roentgenographic appearance and the famous roentgenogram of the hand with two rings* of the anatomist von Kölliker were there. Reminding one of the thoroughness of his investigations of the unknown rays were the electromagnet for testing deflections, prisms of glass, hard rubber and aluminum for trying possible refractions, a jar for demonstrating ionization of air, and a sheet of lead with win-

FIG. 3*b*. Another view of Röntgen's desk and mementoes.

* The roentgenogram of the hand of Röntgen's wife showing one ring is given as the first made; that of von Kölliker the second.

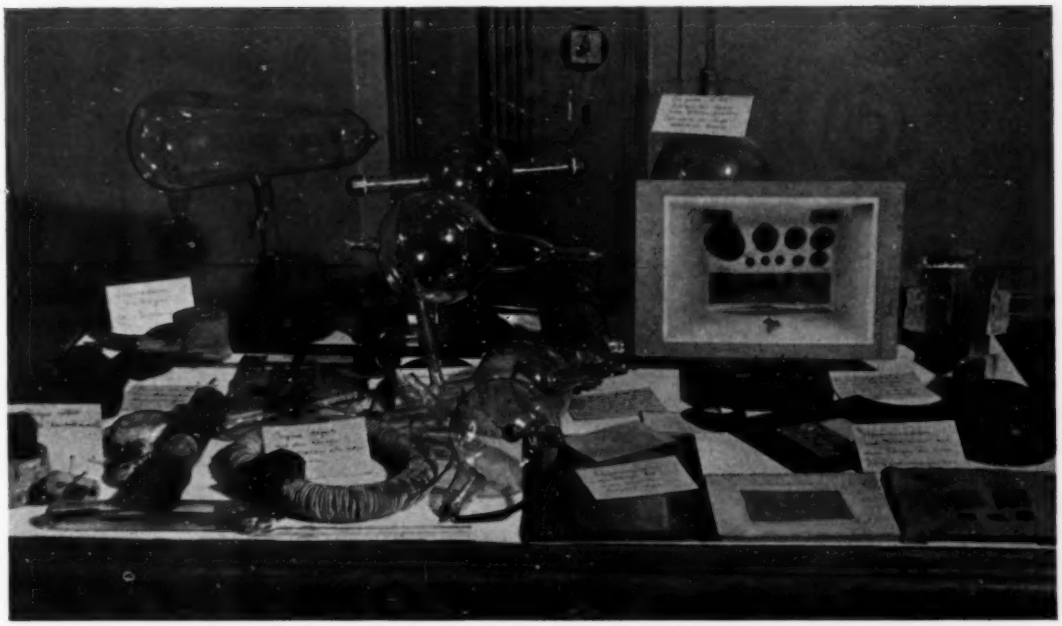

Fig. 3c. Here shown are Crookes tube, left background, several Hittorf tubes in center, glass jar for ionization of air with print of box of weights standing against it; prisms along right edge with masks of lead and aluminum in right foreground. In left foreground at very edge an "absolute evacuated" tube (Röntgen used many of these) with electromagnet beside it.

Fig. 4. University of Würzburg showing from left to right: Physical Institute, Physiological Institute, Anatomy Institute.

dows cut out for measuring absorption by various metals (Fig. 3*c*). Also preserved in the room were his Alpine attire and staff, fishing and hunting equipment, as well as many stereoscopic views of scenes he had visited, attesting to his interest in these avocations.

Today Würzburg, with its crumbled ruins, stands as an example of the vengeance wreaked on Nazi Germany because of its intolerable doctrines, while safe and unscathed the mementoes of Röntgen rest securely in the Physical Institute. This will be welcome news to many, especially to those whose dreams for the future have included a plan for a pilgrimage to this shrine of Roentgenology.

Pinewood Farm,
Warrendale, Pa.

Blackstone Studios, Inc., New York

G. FAILLA
Caldwell Lecturer, 1945

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PROTECTION AGAINST HIGH ENERGY ROENTGEN RAYS

CALDWELL LECTURE 1945*

By G. FAILLA

Radiological Research Laboratory, Department of Radiology, Columbia University

NEW YORK, NEW YORK

1. INTRODUCTION

THE problem of protection is an appropriate one to discuss in a Caldwell Lecture, for the great pioneer, Eugene Wilson Caldwell, in whose honor the Lecture has been established by the American Roentgen Ray Society, died at the height of his career as a result of overexposure to roentgen rays. Also, Caldwell was an engineer before he became interested in medicine and the protection problem in its practical applications is essentially an engineering one.

At the expense of untold suffering and early demise of many such pioneers, radiologists soon became aware of the insidious nature and seriousness of roentgen-ray hazards. The problem of protection, therefore, has been studied for many years and a large body of useful knowledge has accumulated. Today the means of protection can be provided readily but the utilization of these means is not always carried out effectively. In the ultimate analysis the human element is always present—and as ever unpredictable in individual instances. The occurrence of roentgen-ray injuries cannot be eliminated completely, but by persistent effort the frequency can be greatly reduced.

During the war period, a great extension of the use of roentgen rays in industry has taken place. Roentgenography of materials bids fair to compete with medical roentgenography in volume of work. Higher and higher voltages are demanded in this field. There are at present only a few so-called supervoltage machines (1 million volts or over) used for therapeutic purposes, whereas more than seventy are in operation in industrial plants. Two million volt machines are now commercially available. Twenty million and even 100 million volt roentgen generators have been built and used. The rapid increase in the number (and power) of roentgen-ray installations makes protection a matter of considerable social significance. Safety codes are now being formulated under the auspices of the American Standards Association. Wisely it was decided to make these codes applicable only to industrial roentgen-ray installations, where conditions are quite different from those obtaining in the medical field. However, these codes may—and probably will—form the basis for regulatory codes relating to radiological installations.

The work in connection with the above mentioned codes has brought to the fore certain gaps in quantitative experimental data needed for the most satisfactory solution of protection problems. With the available information we can at present provide adequate protection in installations operating at voltages up to 1 million and even 2 million. We do this not by exact calculations but by the use of more or less empirical relations and estimates based on past experience. Accordingly it is always necessary to introduce a factor of safety. If, upon completion of an installation, dosage rate measurements are made and it is found that the safety factor used was too large, the cost of the protective barriers was higher than necessary. If the measurements reveal insufficient protection, the cost and inconvenience of alterations are out of proportion to the initial cost. This economical aspect of the problem becomes more important with increase in voltage.

* Caldwell Lecture to have been given before the American Roentgen Ray Society at the 1945 meeting which was canceled.

In the present paper no attempt is made to fill the gaps in the available technical data. If anything, they are made more prominent. The object of the paper is twofold: (1) to present a simple method for the solution of protection problems, so far as the mathematical steps are concerned; (2) to suggest a method for the determination of absorption curves of more direct application to the protection problem, especially in the high energy range. The interaction of radiation and matter and the interpretation of absorption curves are discussed somewhat at length since they are of fundamental importance. Finally, some interesting problems of measurement, peculiar to very high energy roentgen rays (20 to 100 million volts) are touched upon.

2. SOLUTION OF PROTECTION PROBLEMS IN TERMS OF THE HALF-VALUE LAYER

Given a source of radiation, we may protect ourselves by staying at a long distance therefrom or by interposing a sufficiently thick absorbing barrier between the source and our bodies. Let us assume that the dosage rate at 1 meter from the source is 1 r/min. To determine accurately the distance at which the dosage rate is 12.5 mr/hr.*—the permissible value for continued daily exposure of the whole body—it is necessary in general to take into account the interaction of roentgen rays and matter in the radiation field (air, ground and neighboring objects) even when no solid barrier is in the path of the direct rays. However, for the moment we shall neglect the influence of matter present in the radiation field and, therefore, we may calculate the desired distance on the basis of the inverse square law alone. It is $x = \sqrt{\frac{60{,}000}{12.5}}$ =69.3 meters. Having neglected the influence of matter on the dosage rate, this distance is independent of the quality of radiation. It applies to any (point) source of roentgen rays producing a dosage rate of 1 r/min. at a distance of 1 m.

The second part of the problem is to calculate the thickness of the protective barrier necessary to reduce the dosage rate to 12.5 mr/hr. at a given distance (shorter than 69.3 m.). This will depend on the quality of radiation and the kind of absorbing material used. However, the calculation may be made in two steps, of which one is independent of both quality of radiation and kind of material.

It is obvious that the dosage rate at the point in question may be reduced to one-half its initial value by interposing between the two a suitable absorbing barrier of a certain definite thickness. This is called the half-value layer (hvl). We shall assume for the moment that interposing a second barrier of the same material and thickness again reduces the dosage rate by one-half, which therefore becomes one-fourth of the initial value. Addition of a third half-value layer reduces the dosage rate to one-eighth of the initial value, and so forth.

Returning to the example, we may now ask: How many half-value layers are required to reduce the dosage rate from 1 r/min. to 12.5 mr/hr.? The reduction factor is 60,000/12.5 = 4,800. Therefore, the required number, n, of half-value layers is $2^n = 4{,}800$ or $n = 12.2$. Obviously, this number is independent of the quality of radiation and the kind of material of which the barrier is made. To determine the actual thickness of the barrier it is necessary to know also the numerical value of the half-value layer for the quality of radiation and kind of material in question. Thus, if in the above example the half-value layer is 1 mm. of lead, the barrier must be 12.2 mm. thick to reduce the dosage rate to 12.5 mr/hr. at a distance of 1 meter from the source.

In practice protection is generally brought about by a suitable combination of distance and barrier. We shall assume for convenience that the radiation output of the machine is expressed in roentgens per minute at a distance of one meter. Let

* It is becoming common practice in the art of radiation protection to express doses and dosage rates in terms of a smaller unit than the roentgen. A convenient subunit is the milliroentgen of which one thousand equal one roentgen (1,000 mr = 1 r and 12.5 mr/hr. = 0.0125 r/hr.).

R_1 represent this dosage rate. At any other distance x meters, the dosage rate will be $R_x = R_1/x^2$ r/min. If R_1/x^2 is greater than 12.5 mr/hr. (0.000208 r/min.) a protective barrier must be provided. Following the procedure outlined above, we may express the thickness of the barrier in terms of the number n of the appropriate half-value layer

$$2^n = \frac{R_1}{0.000208x^2} = \frac{4800R_1}{x^2}$$

$$n = 12.2 + 3.32 \log R_1 - 6.65 \log x \cdots. \quad (1)$$

The physical interpretation of the above equation facilitates the solution of protection problems. It is obvious that when the radiation output is doubled, the thickness of the protective barrier must be increased by 1 half-value layer; when it is quadrupled, 2 half-value layers must be added, and so on. The mathematical relation between the number n_R of additional half-value layers and dosage rate R_1 is

$$n_R = 3.32 \log R_1 \cdots. \quad (2)$$

Similarly when the distance is increased, the thickness of the protective barrier may be reduced by a number n_x of half-value layers given by the expression

$$n_x = 6.65 \log x \cdots. \quad (3)$$

Comparing the three equations it will be seen now that the total number of half-value layers required in a protective barrier consists of three parts: (a) A constant number (12.2) which is necessary to reduce the dosage rate at 1 meter distance from 1 r/min. to 12.5 mr/hr. (b) The number which must be added if the dosage rate at 1 meter is greater than 1 r/min. (or subtracted if less). (c) The number which must be subtracted if the distance is greater than 1 meter. In terms of half-value layer, therefore, the problem is reduced to one of algebraic addition instead of multiplication and division. This makes possible its solution by simple graphical means.

The simplest scheme is, perhaps, to take care of each part of the problem separately. This can be done by means of the first two sets of scales in Figure 1. An example will illustrate their use. Determine the thickness of the necessary barrier, in terms of half-value layers, when the roentgen-ray output is 90 r/min. at 1 meter and the region to be protected is at a distance of 8 meters from the target—protection being based on the permissible dosage rate of 12.5 mr/hr. From scales *A–B* it will be seen that the number of half-value layers for a roentgen-ray output of 90 r/min. at 1 meter is 6.5. Similarly from scales *C–D* it is found that for a distance of 8 meters the number of half-value layers to be subtracted is 6. Therefore, the total number n required is (eq. 1)

$$n = 12.2 + 6.5 - 6$$
$$= 12.7 \text{ hvl.}$$

It will be recalled that with an output of 1 r/min. at 1 meter, the distance required to reduce the dosage rate to 12.5 mr/hr. is 69.3 meters. Since this is a longer distance than is usually encountered in practical problems, the constant term (12.2 hvl) and the distance term (6.65 log x) may be combined as shown in scales *E–F*. For the appropriate distance on scale *E* we then read directly on scale *F* the difference between 12.2 and the distance term. Solving the same problem by means of these scales we find on scale *F* that 6.2 hvl are required when the distance on scale *E* is 8 meters. This is equal to 12.2–6 in eq. (1) as previously found. The output term is determined by means of scales *A* and *B* as before.

In planning roentgen-ray protection it is always safest to assume continuous operation of the machine. This has been done in the above example. However, sometimes this is not done and allowance is made for the time that the machine is in actual operation in the course of an eight hour day. If in the above example we assume that the machine operates not more than four hours a day, we may solve the problem by taking for the roentgen-ray output a proportionately lower value, that is, 45 r/min. at 1

meter. Then from scales *A–B* we find that the required number of half-value layers for this output is 5.5 and the total number is now 11.7 instead of 12.7. Incidentally, this result brings out how little is gained by taking into account the time during which the machine is not in operation. Limiting the running time to one-half of the eight hour working day reduces the thickness of the protective barrier by 1 half-value layer which in this case is less than 10 per cent of the total. Once the barrier has been installed the limitation on the operating time remains. Subsequent additions to the protective barrier always cost more. Whenever the question comes up in practice all factors should be considered carefully. Sometimes, in special cases, it is advantageous to take into account the actual running time of the equipment and the degree of occupancy of the regions to be protected.

The scales of Figure 1, of course, may be used to solve other problems. To give another illustration we shall solve the above problem in reverse. In an existing installation it is found that the operator is at a distance of 8 meters from the target. The intervening barrier is 11.7 hvl thick. The output of the machine is 90 r/min. at 1 meter. How many hours during an eight hour working day can the machine be run, without exposing the operator to more than 0.1 per day? From scales *E–F* we find that the constant term and distance term combined require 6.2 hvl for a distance of 8 meters. Therefore, $11.7 - 6.2 = 5.5$ hvl of the barrier remain to take care of the output term. From scales *A* and *B* we find that 5.5 hvl correspond to an output of 45 r/min. at 1 meter. With this output the dosage rate in the protected region is 12.5 mr/hr. Since the actual output is 90 r/min. at 1 meter, the dosage rate in the protected region is 25 mr/hr., and therefore the operator is exposed to the permissible daily dose of 0.1 r in four hours of actual operation of the machine.

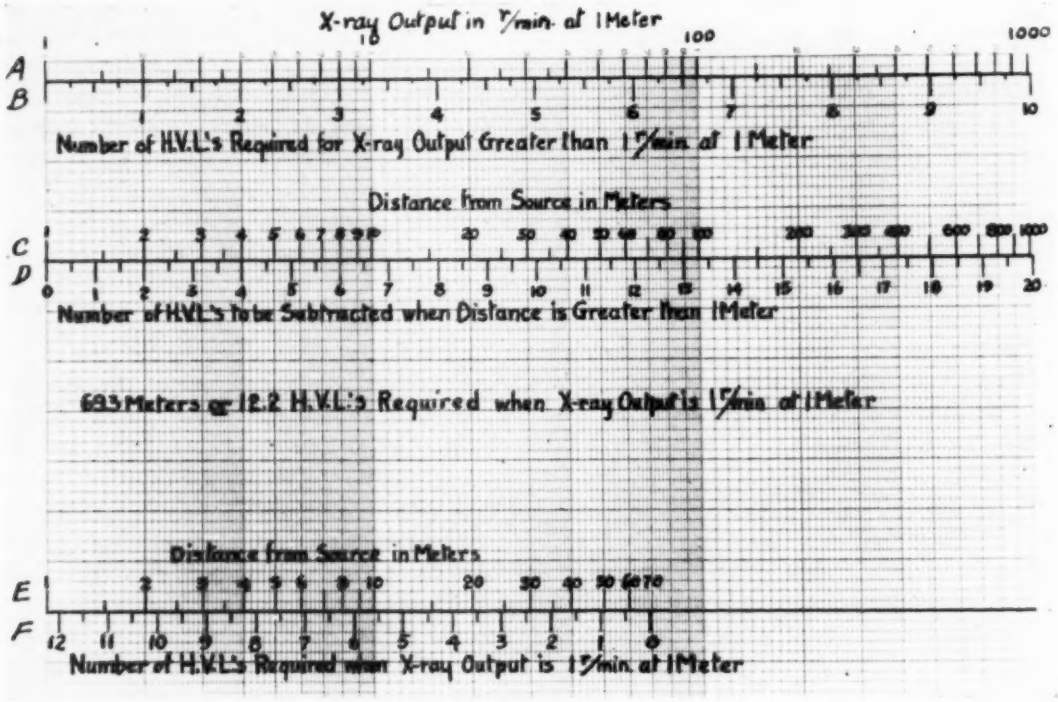
X-ray Output in r/min. at 1 Meter
A
B
Number of H.V.L.'s Required for X-ray Output Greater than 1 r/min. at 1 Meter
Distance from Source in Meters
C
D
Number of H.V.L.'s to be Subtracted when Distance is Greater than 1 Meter
693 Meters or 12.2 H.V.L.'s Required when X-ray Output is 1 r/min. at 1 Meter
Distance from Source in Meters
E
F
Number of H.V.L.'s Required when X-ray Output is 1 r/min. at 1 Meter

FIG. 1

It should be noted that the scales of

Figure 1 are independent of the unit of distance used, provided the output is expressed in r/min. at *unit* distance. To illustrate this point we shall solve the above example in terms of feet. The output of 90 r/min. at 1 meter corresponds to 970 r/min. at 1 ft. The 8 meter distance equals 26.3 ft. We shall use scales *E–F* as if scale *E* had been graduated in feet. At the 26.3 point on scale E we obtain 2.8 hvl on scale *F*. At the 970 point on scale *A* we read 9.9 hvl on scale *B*. While the two terms are quite different, their sum, $2.8+9.9=12.7$, is the same as before.

In practice it is customary to state the output of a roentgen-ray machine in r/min. at a point in the center of the *useful* beam at a "standard" distance from the target. In roentgen therapy this distance is usually 50 cm.; in industrial roentgenography it is 1 meter. As indicated above, the latter is more convenient for the present purpose. However, it is important to note that the roentgen-ray output to use in designing protective barriers is not necessarily that in the direction of the useful beam. The same thing applies to the half-value layer. This point is not important in dealing with ordinary roentgen rays because there is little difference in intensity and quality with respect to angle; and, also, because protective barriers are not expensive. In the supervoltage region and beyond, however, it is economically worth while to take advantage of the non-uniformity in angular distribution of the emitted radiation, as regards both intensity and quality. When the roentgen tube is fixed in position, or its angulation is limited, some of the necessary barriers may well be designed on the basis of the lower output and lower penetrating power of the radiation in certain directions. In such cases, the dosage rate at 1 meter (as well as the half-value layer) to be used in connection with Figure 1 is that in the direction under consideration and not that of the useful beam.

In this connection another advantage of the half-value layer scheme of solving protection problems may be pointed out. If the radiation output in r/min. at 1 meter is known in all directions around the target for the unshielded roentgen tube, one may determine the total number of half-value layers required in any direction to protect personnel from the direct radiation. This number of half-value layers may then be provided partly by a lead enclosure around the tube and partly by a lead lined or concrete wall. Or, similarly, the number of half-value layers embodied in the tube shield may be subtracted from the total number required to obtain the number of half-value layers that the protective barrier must provide. It should not be forgotten in this connection that a separate allowance must be made for scattered radiation that may reach the wall. We are now considering only protection against direct radiation emitted at the target.

Certain useful relations derived from the scales of Figure 1 may well be mentioned at this point. It will be noted by inspection of scales *A–B* that a factor of 10 corresponds to 3.32 hvl ($10=2^{3.32}$); a factor of 100 to 6.65 hvl; and a factor of 1000 to 9.97 or practically 10 hvl. This relation is particularly useful in determining the half-value layer from an absorption curve plotted on a semilogarithmic scale. If the straight line portion of the curve covers three cycles, it is only necessary to read the difference in the thickness of absorbing material for the three cycle span and to divide this by 10 to obtain the half-value layer. Having determined the half-value layer one may calculate the absorption coefficient from the relation $\mu=0.693/\text{hvl}$. For a one cycle span the dividing factor is 3.32, etc.

Comparison of the two sets of scales *A–B* and *C–D* reveals that for the same numerical value on scales *A* and *C*, the number of half-value layers on scale *D* is just double that on scale *B*.* Accordingly only one set of scales *A–B* is necessary for the solution of the problem. The output term of equation (1) is determined by reading the number of half-value layers directly on scale *B*.

* This is obvious to those familiar with logarithms.

The distance term is obtained by using scales *A–B* and doubling the number of half-value layers. With this in mind attention may be called to the fact that the ordinary polyphase slide rule has two scales like *A* and *B* in Figure 1. The scale corresponding to *A* is the 3-cycle log scale used to determine the cube of a number. The scale corresponding to *B* is the linear scale on the reverse of the slider used to determine the logarithm of a number. This scale on the slide rule is slightly shorter than it should be to correspond exactly to scale *B* of Figure 1. However, the difference is only 0.24 of 1 per cent and may be neglected. Accordingly, protection problems may be solved (in two steps) by the half-value layer method described here, without constructing special scales. To solve the problem in one step a special slide rule may be constructed. The chart of Figure 2 serves the same purpose. To illustrate its use the solution of the typical problem given as an example before is indicated on the chart by arrows.

In developing the half-value layer method just described it was assumed that interposing a second barrier of equal thickness to the first (1 hvl) the dosage rate would again be reduced by one-half. In other words, it was assumed that the half-value layer has a constant value throughout. In practice this seldom occurs and, therefore, having determined the number of half-value layers needed, we cannot compute the actual thickness of the barrier by simple multiplication. The difficulty is more apparent than real, for, in order to design a barrier by any method we must have, directly or indirectly, the following infor-

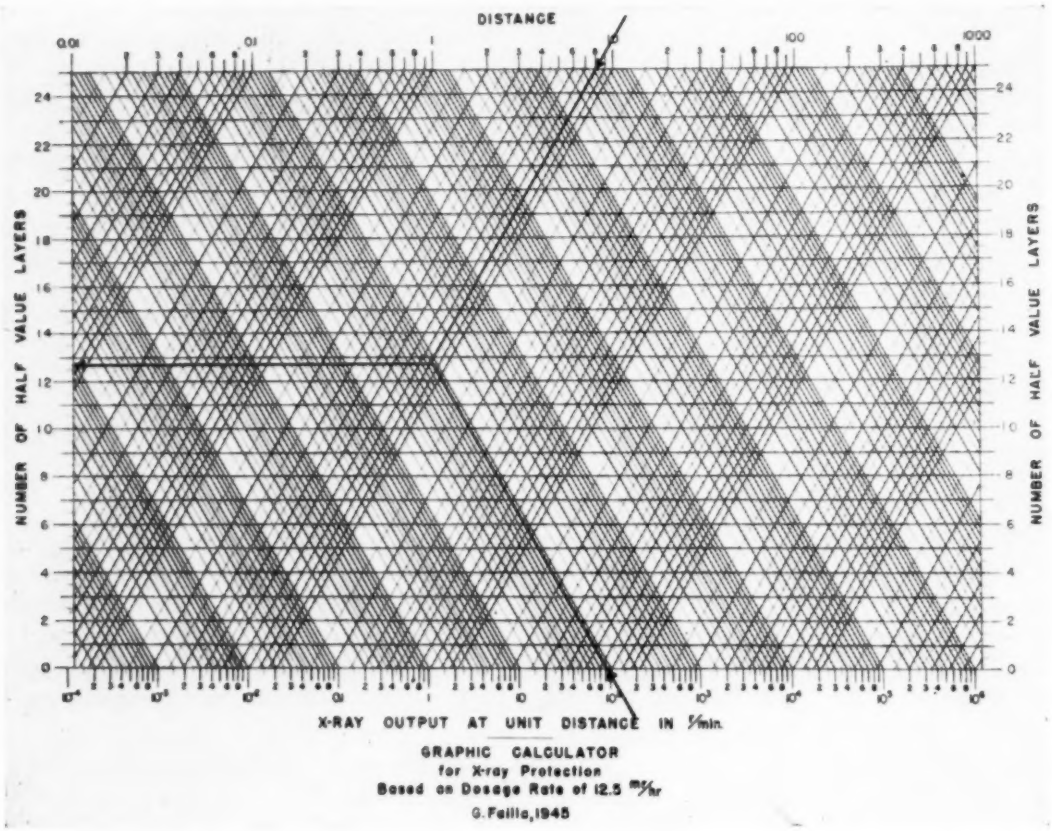
DISTANCE
NUMBER OF HALF VALUE LAYERS
X-RAY OUTPUT AT UNIT DISTANCE IN r/min.
GRAPHIC CALCULATOR
for X-ray Protection
Based on Dosage Rate of 12.5 mr/hr
G. Failla, 1945

FIG. 2

mation: (1) the radiation output of the machine in roentgens per unit time at some convenient distance (1 meter) in the direction in which the barrier is located; (2) the rate at which unit thickness of the barrier decreases the dosage rate, in the given direction, as the thickness of the barrier is increased. This means an "absorption curve" of a particular type, as we shall see presently. Assuming, however, that we have the appropriate absorption curve, the solution of the problem is simple, as may be seen from Figure 3. To the absorption curve, plotted in the customary way on semilog paper, is added a half-value layer scale parallel to the thickness scale. Construction of the half-value layer scale is indicated by the parallel vertical lines stemming from successive 50 per cent points on the curve. If then the calculated number of half-value layers is counted on the half-value layer scale, the corresponding thickness of material may be read on the thickness scale. The absorption curve is used only for the construction of the half-value layer scale and need not be shown in conjunction with the two parallel scales. This procedure presupposes, of course, that the thickness scale of the absorption curve is long enough to include the largest number of half-value layers that may be needed in the design of any barrier for the quality of radiation represented by the curve. This should always be the case for reasons discussed later. If a complete curve is not available, the primary data are insufficient to solve the problem accurately by any method. As an approximation the curve may be extrapolated in a reasonable way. It may be well to mention explicitly at this point an additional condition that the absorption curve must meet. The zero thickness point must correspond to the conditions under which the radiation output was determined; otherwise the output value used in the calculations and the absorption curve are not properly related to each other.

3. ABSORPTION CURVES

In the preceding section, the half-value layer was defined in effect as the thickness of a barrier of any given material such that, when interposed between the source and a given point, it reduces the dosage rate at that point to one-half its initial value. This implies that absorption measurements should be made under the conditions obtaining in any given case. Furthermore, since the dosage rate should be expressed in roentgens per unit time, the measurements should be made with instruments that fulfill the requirements imposed by the definition of the roentgen. Ordinarily absorption measurements are made for a different purpose and the results, in general, are not directly applicable to our problem. Little attention has been paid to this problem in the past because in the voltage range up to 200 or 300 kv. the distinction is of little practical importance. With the more common use of very high voltage roentgen rays the problem assumes greater proportions and it behooves us to examine the situation more closely.

In general, roentgen rays passing through a sheet of matter undergo the following changes: (1) Some are absorbed through the photoelectric process; (2) some are merely deviated from their path without change of wavelength; (3) some are scattered through the Compton process imparting some of their energy to electrons and then proceeding in new directions with increased wavelength; (4) some are transformed into pairs of electrons and positrons endowed with kinetic energy in addition to their mass equivalent energy when the energy of the pair creating photon is in excess of 1,022 kev. These are the primary reactions. It is evident that in going through the absorber the photons produced in the primary reactions will undergo similar changes. Furthermore, some of the resulting high energy electrons will produce roentgen rays. The positrons soon combine with electrons and disappear—are "annihilated"—producing photons of equivalent total energy. The passage of roentgen rays through a thick layer of matter is therefore a very complicated process. Especially in

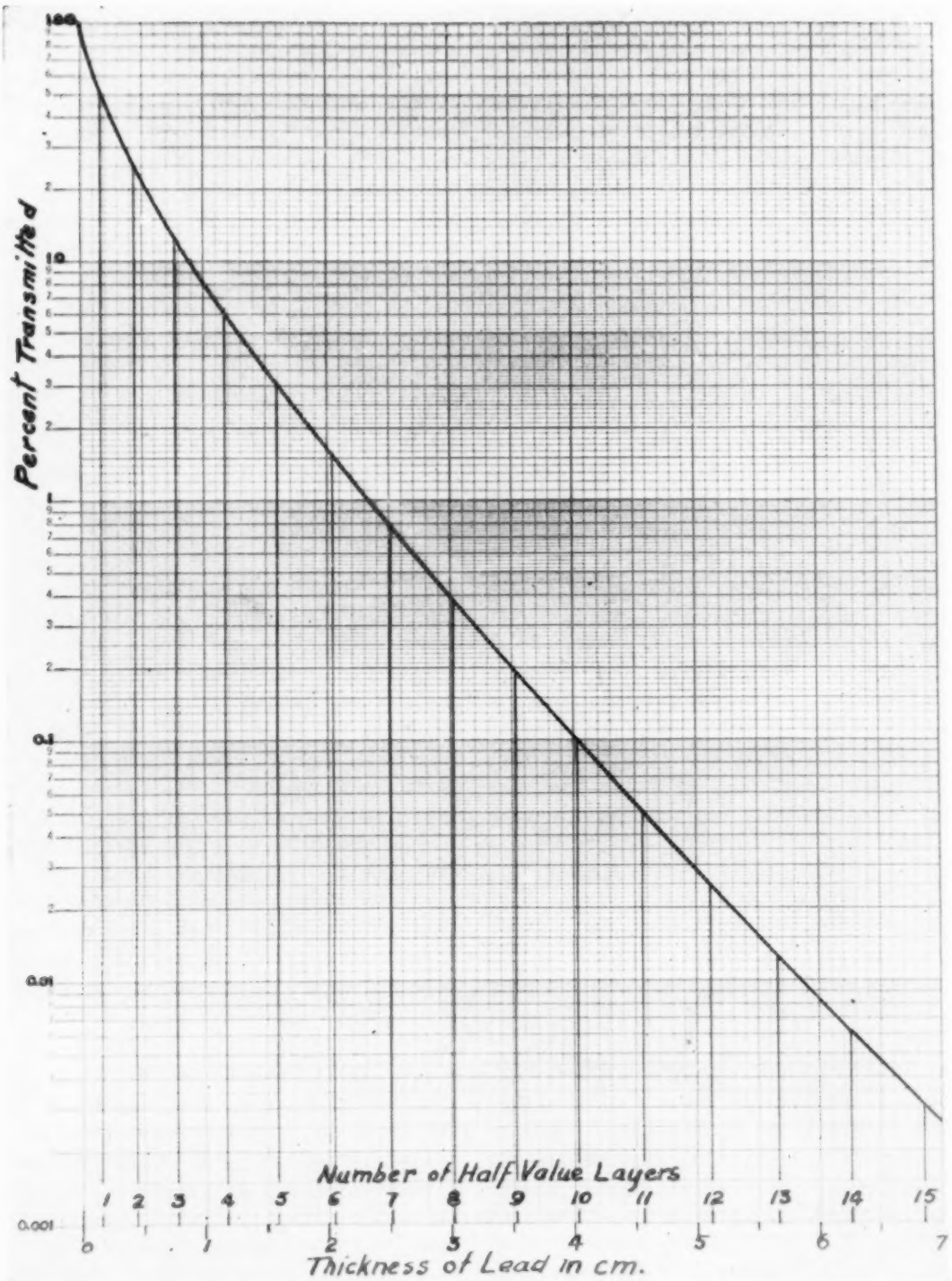
Percent Transmitted
100
10
1
0.1
0.01
0.001
Number of Half Value Layers
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 1 2 3 4 5 6 7
Thickness of Lead in cm.

FIG. 3

the case of high energy roentgen rays and a material of low atomic number the proportion of energy actually absorbed by the sheet of matter is small. Most of it either passes through unaffected or emerges from the material after undergoing certain transformations. In roentgen-ray protection, of course, any radiation that emerges from a barrier is potentially dangerous and must be taken into account. Hence it is of the utmost importance to realize that the usual absorption measurements made in the laboratory are not directly applicable to the protection problem, because scattered and secondary radiations of all kinds are intentionally prevented from reaching the measuring device.*

The experimental setup used for the determination of absorption coefficients is generally as shown diagrammatically in Figure 4.† The beam traversing the absorbing material A is small in cross-section and is delimited by the diaphragm D_1 (which should be of sufficient thickness to stop practically all radiation outside the beam from reaching the absorbing material A). Diaphragm D_2 is provided to allow a very small beam of the transmitted radiation to enter the ionization chamber C. Under these conditions practically all scattered and secondary radiation originating in A is prevented from entering the ionization chamber. Under these conditions and in the case of monochromatic roentgen rays the mathematical relation between the intensity‡ of the transmitted radiation I and thickness of absorber t is

$$I = I_0 e^{-\mu t}$$

where I_0 = intensity of radiation when no absorber is present

μ = "linear absorption coefficient," or, simply, absorption coefficient

A vast amount of work has been done during the last thirty years to determine the coefficients of absorption for different wavelengths and different materials. Numerical values are given in manuals and books on roentgen rays dealing with the subject. In the supervoltage region and beyond, actual measurements have been few but theoretical calculations are more valid, and reliable values of the absorption coefficients for monochromatic radiation are available up to many millions of volts. However, the point we wish to emphasize here is that whether obtained by measurement or calculation, the absorption coefficient generally given in tables is not the proper one to use in determining the thickness of a protective barrier. As already pointed out, in experiments planned to determine the absorption coefficient, it is desired to exclude from the transmitted radiation all scattered and secondary radiation originating in the absorber. The ab-

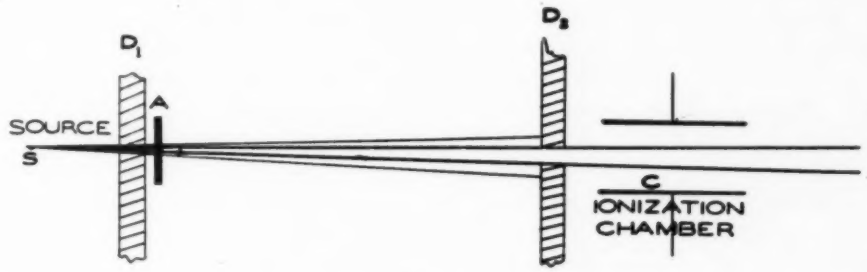

FIG. 4

* The intent is always there but the attainment of this desideratum is not always realized. This is one of the factors accountable for the discrepancies existing in published values of absorption coefficients.

† When monochromatic roentgen rays are used the source in the position shown is not the focal spot of the roentgen tube. This is irrelevant to the present discussion.

‡ Intensity = energy flux per unit area. In the case under consideration, by assumption, the quality of the radiation passing through the ionization chamber is always the same and therefore the ionization chamber reading is proportional to the intensity of radiation. (See later.)

sorption coefficient, as ordinarily defined, is in reality an attenuation coefficient. The transmitted radiation as measured is less intense (that is, has been attenuated) not only because the layer of matter has transformed some of the energy of the beam into something other than ionizing radiation, but also because some ionizing radiation of the original beam and most of that originating in the absorber is deviated out of the narrow beam entering the ionization chamber.

The relative importance of the different processes by which a narrow beam of roentgen rays is attenuated depends on the wavelength of the radiation and the nature of the material traversed. The coefficient μ may be broken down into separate components each referring to a specific process.

$$\mu=\tau+\sigma_s+\sigma_a+\sigma_p{}^*$$

where τ refers to the photoelectric process

σ_s refers to attenuation caused by transfer of energy to the photon in the Compton scattering process

σ_a refers to attenuation caused by transfer of energy to the electron in the Compton scattering process

σ_p refers to the pair formation process

In discussing the relative values of these coefficients, the different wavelength regions may be expressed to advantage in terms of the corresponding photon energies given by the formula:

$$\text{kev.}=\frac{12.4}{\lambda}$$

where λ = wavelength in Ångströms
and kev. = photon energy expressed in electron kilovolts or kilo-electron-volts.

For convenience, the term kilovolts is often used in this connection instead of electron kilovolts. The term mega-electron-volts, mev., or million electron volts, has found wide acceptance among physicists, and in conformity with this notation, it is well to use the term kilo-electron-volts, kev. In this paper kev. is used only to express the photon energy in the case of monochromatic radiation. The term kv. is used to indicate the maximum voltage applied to a roentgen tube. Thus 200 kv. roentgen rays are those produced in a tube to which a (peak) voltage of 200 kv. is applied. Only a small percentage of the emitted photons have an energy of 200 kev., the others have less energy. It is well to remember therefore that 200 kev. roentgen rays are much more penetrating than 200 kv. roentgen rays in this notation.

Returning to the discussion of the absorption coefficient, we shall point out first that the photoelectric component τ predominates over all others in the case of low voltage roentgen rays and high atomic number elements. For lead τ is large up to 500 kev.. and appreciable even at 2,000 kev. (2 mev.) For aluminum it is large only up to about 50 kev. The two Compton components $\sigma_s+\sigma_a$ for the same two materials predominate beyond the energy limits just given until pair formation becomes important. The latter occurs at energies higher than 5 mev. for lead and 15 mev. for aluminum. In Figures 5 and 6 it may be seen at a glance how the relative contributions of the three different components vary with photon energy in two extreme cases: lead and air. The solid curves represent the sum of the three components, that is μ. It is interesting to note that for lead μ has a minimum value at about 3.5 mev. This means that as the energy of the radiation increases up to 3.5 mev. lead becomes more "transparent." With further increase in energy, however, it becomes again less transparent.

At least in the photon energy region in which the Compton effect predominates, it is evident that "absorption" consists largely of deviation of radiation out of the

* The term referring to the simple scattering process without change of wavelength is omitted since it is negligible in the wavelength region of present interest (in which the wavelength is short in comparison to the dimensions of the atom).

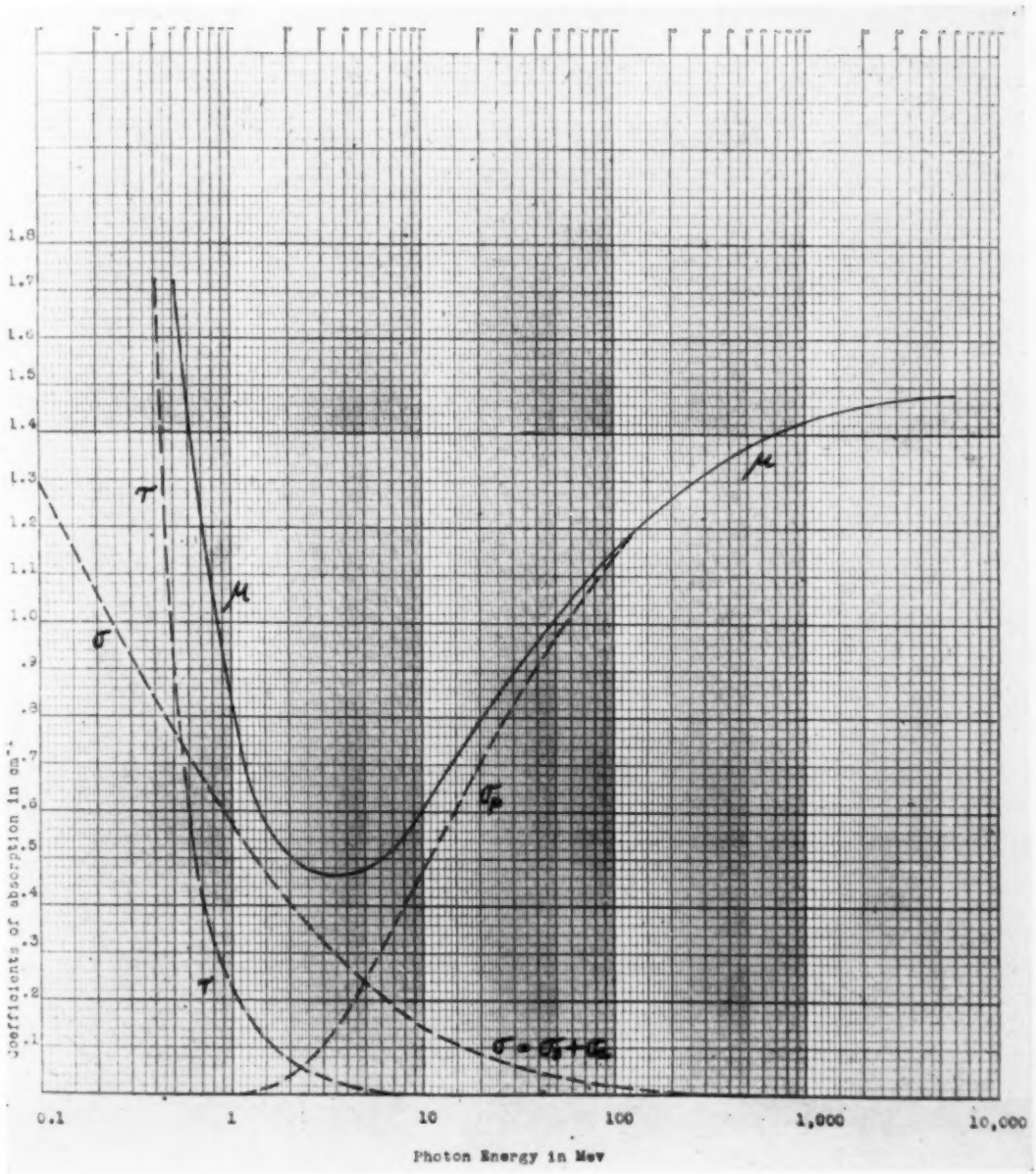

Fig. 5

narrow beam entering the measuring device. Actual absorption of energy by the material occurs through the absorption of the secondary electrons produced in the interaction of radiation and matter. In the case of the photoelectric effect all the energy of the primary photon is transferred to an electron. However, this process takes place only with electrons that are strongly bound and the kinetic energy of the electron after leaving the atom is less than that imparted to it by the photon. The balance of the energy reappears in the form of radiation as soon as another electron fills the place in the atom left vacant by the ejected photoelectron. For the K level in the lead atom the energy that reappears in the form of a photon amounts to 87 kev., and is therefore quite penetrating. This fluorescent radiation is emitted in all directions.

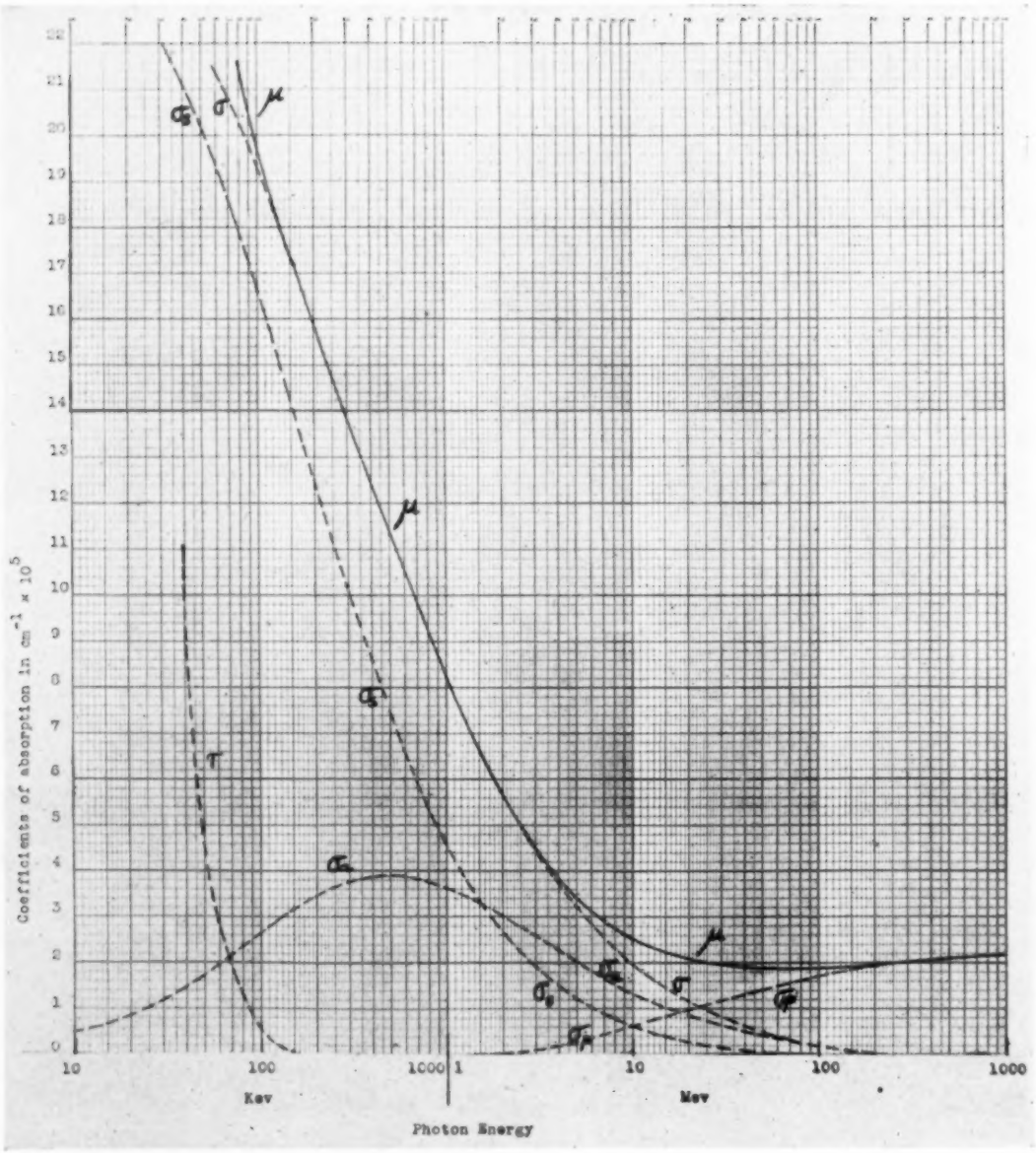

FIG. 6

In the case of the Compton effect σ_a represents the fraction of the primary photon energy transmitted to the electron and σ_s the fraction imparted to the secondary photon. The relation between the two varies with the energy of the primary photon. In the lower energy range σ_s is larger than σ_a. The two are equal when the photon energy is 1.5 mev. and both decrease rapidly at higher energies. The Compton scattered photon travels more and more in the forward direction as the energy of the primary photon increases.

In the pair formation process the energy of the photon is transferred to the newly created electron and positron pair. If the energy of the photon is larger than 1,022 kev., the difference appears as kinetic energy of the electron and positron together (not necessarily equally divided between the two). When the kinetic energy of the electron (or positron) thus produced

is not large, this kinetic energy is absorbed by the material more or less *in situ*. When it is very large, much of it is transformed into photons. It is interesting to note that at energies much beyond the 3.5 mev. point (for which the absorption coefficient in lead is a minimum) some of the photons thus produced, and some Compton photons for that matter, may be more penetrating *in lead* than the original photons. In this region, also, the energy exchange from electrons to photons, or the reverse, takes place largely in the forward direction. The positron of the pair may be annihilated while it still possesses considerable kinetic energy, but more often it is annihilated after it has stopped. In general two photons, each of 511 kev. energy and traveling in opposite directions, are produced in this process.

From the foregoing, two things are evident: (1) the interaction of photonic radiation and matter gives rise to other photonic radiation; (2) the "secondary" photons have less energy than the primary ones. Now in discussing the experimental setup of Figure 4 it was stated that the aperture of the second diaphragm D_2 should be small enough to prevent any secondary or scattered radiation from entering the ionization chamber. In practice this condition becomes more difficult to meet as the energy of the radiation increases. As the thickness of the absorber becomes large (at high voltages) the beam spreads out considerably by "forward" scattering and a relatively large volume of the material can send radiation through the limiting diaphragm of the chamber. Furthermore, since in the parallel plate type of chamber, ions are collected from a much larger air volume than that actually traversed by the beam, any unwanted radiation passing through the diaphragm is apt to register. For the same reason (large ion collecting volume) the limiting diaphragm D_2 must be much thicker than the maximum thickness of absorber used, in terms of equivalent absorption. At any rate, some secondary and scattered radiation does enter the chamber. Since the energy of these photons is lower (or the wavelength longer) the ionization chamber reading is, in general, not proportional to the intensity of radiation. Actually, in practice, instead of the parallel plate chamber of Figure 4, a closed chamber of some sort would be used in the high energy range. The relation between ionization chamber reading and intensity of radiation is then more complex.

Inasmuch as for protection purposes we wish to measure radiation in roentgens, we shall assume that the small closed chamber is constructed of air equivalent materials. Also we shall assume that the wall thickness is equal to the range of the highest energy secondary electrons. We shall consider first the voltage range in which pair formation is negligible. The ionization in the chamber is due to that part of the energy abstracted from the beam of radiation that is capable of producing ionization *in situ*. This means the secondary electrons produced by the photoelectric and Compton process in air.* In the notation of the absorption coefficient μ, τ represents the fraction of the energy removed from the beam by the photoelectric process. In air the binding energy of the K electrons is small, and therefore substantially all the energy imparted to the electron is available to produce ionization. In the Compton effect, the portion of the energy transferred to the electron is represented by σ_a. Therefore, $\tau+\sigma_a$ represents the fraction of the energy of the radiation beam responsible for the ionization. If I is the energy flux per unit area, the ionization current in the air chamber will be

$$(i.c.)=CI(\tau+\sigma_a)_A$$

where C = a constant
and $(\tau+\sigma_a)_A$ refers to air.

So long as the wavelength of the radiation entering the chamber remains the same $(\tau+\sigma_a)_A$ is constant and the ionization current is strictly proportional to the intensity

* The wall is air equivalent by assumption.

of radiation (energy flux per unit area). In this case the exponential law of absorption may be put in terms of the ionization current

$$(i.c.)_t = (i.c.)_0 e^{-\mu t}.$$

We have found, however, that in practice, the quality of the radiation reaching the chamber is altered by the admixture of scattered and secondary radiation produced in the absorbing material in various ways. Accordingly, the relation between ionization current and thickness of absorber should not be exponential on the basis of a change in quality *per se*, without even considering the increase in the energy flux reaching the chamber caused by the secondary and scattered radiation. In practice the latter is more important, as we shall see presently.

In Figure 7 are plotted the values of τ, σ_a and $\tau+\sigma_a$ for air for different photon energies from 40 kev. to 10 mev. The values of σ_a are derived from the Klein-Nishina formula, which has been found to be quite reliable. The values of τ are difficult to obtain in that no satisfactory theoretical relation with wavelength has been worked out. The values in the table have been derived by graphical means from published tables of absorption coefficients and other information in the literature. The experimental data available are numerous but not very concordant, and the accuracy of the derived value of τ suffers from this fact. This, however, has little influence on the conclusion we wish to draw, namely, that since $(\tau+\sigma_a)_A$ (Fig. 7) remains between 3 and 4 $\times 10^{-5}$ cm.$^{-1}$ in the energy range of 100 to 2,000 kev., the quality effect on the relation between ionization current and energy flux through the chamber is not very marked in this range. If softer radiation (energy less than 100 kev.) reaches the chamber the

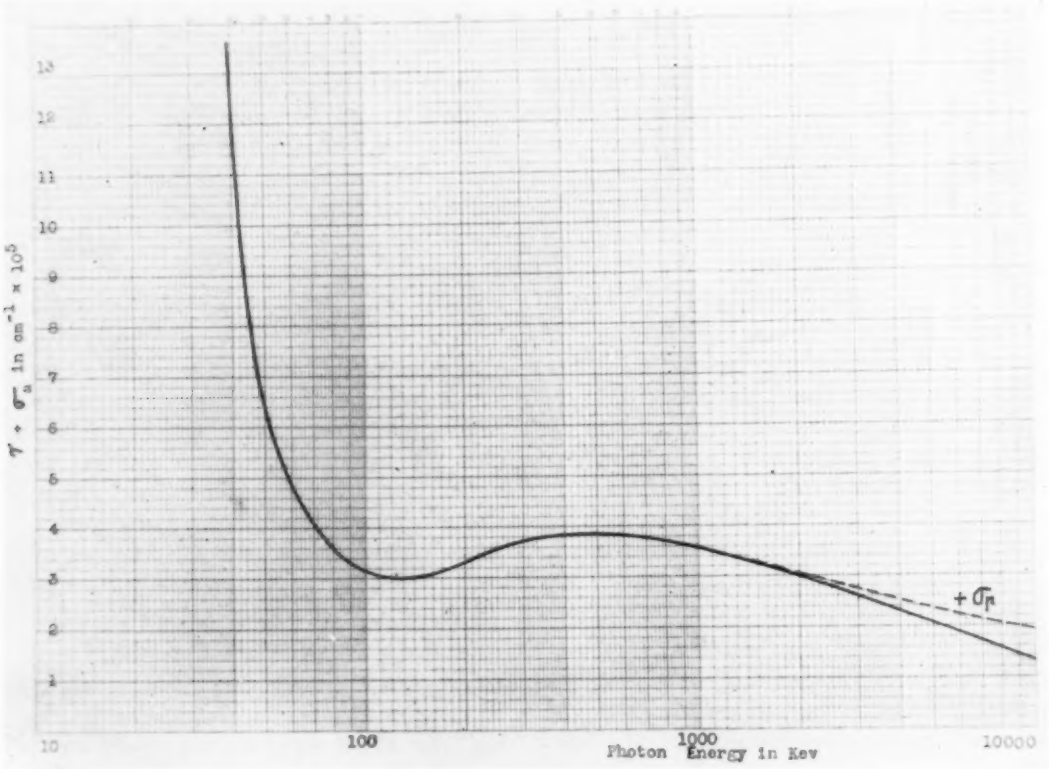

FIG. 7

effect may be considerable in proportion to the relative amount of such radiation with respect to the primary and the difference in the values of $(\tau+\sigma_a)_A$.

We shall now consider the influence of the energy flux contributed by the scattered radiation. It is obvious that the ionization chamber reading will be higher than it would be otherwise. It is also obvious that the amount of scattered radiation reaching the chamber must depend on the thickness of the absorber, other things being equal. In accordance with the processes of attenuation previously described—largely the Compton effect, in the present case—more and more of the primary radiation is scattered as the thickness of the absorber increases. However, since the wavelength is longer, this radiation is attenuated more readily by the material in which it is produced, and therefore the amount emerging from the absorber cannot increase indefinitely. Beyond a certain thickness an additional layer of the material adds as much scattered radiation as it prevents from coming out and the relative proportions between directly transmitted radiation and scattered radiation remain constant. The "absorption" curve plotted on semilog paper would be of the form shown in Figure 8 (*a*). The mathematical relation would be

$$I=I_0e^{-\mu(t-t_e)}$$

where t_e = the thickness of absorber indicated in the figure. It is the thickness necessary to bring the scattered and secondary radiation "in equilibrium" with the primary radiation, and may be called the equilibrium thickness. The value of μ obtained from this curve is the same as it would have been if no scattered radiation had been allowed to reach the ionization chamber. This is because the experimental conditions were assumed to be such that beyond a certain thickness of material the relative proportions of directly transmitted radiation and scattered radiation remained constant. (In addition, we are now considering only monochromatic radiation.)

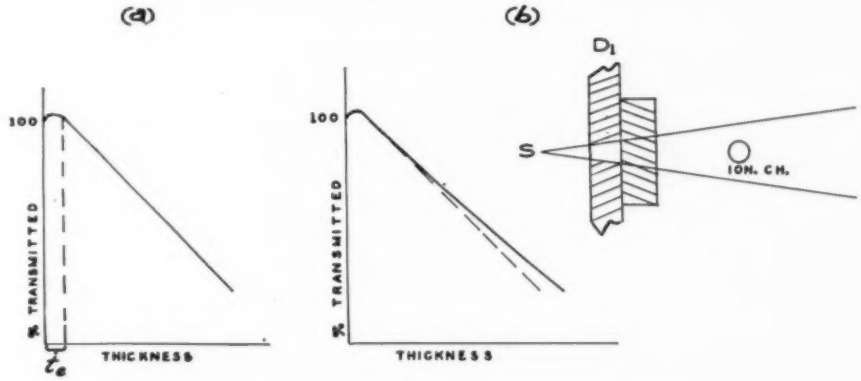

Fig. 8

When the proportion of scattered radiation reaching the chamber changes with the thickness of the material the absorption curve is not a straight line. This is illustrated in Figure 8 (*b*). Here the thickness of the absorber is about one-half of the distance between the diaphragm and the chamber. The last layer of absorber, therefore, is much closer to the chamber than the first, and contributes more scattered radiation to the chamber. If the radiation in case (*b*) is of the same wavelength as in (*a*), the absorption curve will differ from the straight line of (*a*) in the manner shown approximately in (*b*). The radiation, although monochromatic, does not give a straight line absorption curve on a semilog plot, and μ appears to vary with the thickness of the absorber. Experimentally the influence of this effect may be checked readily by taking readings with a thickness

of material of the order of magnitude of the equilibrium layer at different levels between the disphragm and the chamber.

The setup of Figure 8 (*b*) appears exaggerated if one thinks of the source as being a supervoltage roentgen tube, in which case the intensity of radiation is high and long distances can be used. When the source is a radioactive isotope,* however, the distance at which measurements can be made is quite limited.

There are many other experimental difficulties involved in the measurement of absorption coefficients in the case of high energy monochromatic radiation. Some of these will become apparent in the discussion of the more practical problem of the measurement of polychromatic radiation.† In physics the study of absorption coefficients of monochromatic radiation has made possible our understanding of the interaction between radiation and matter through the different processes already described. To make use of this background in the simplest fashion we should make measurements of polychromatic radiation under the conditions approximating most closely those required for the proper measurement of absorption (i.e. attenuation) coefficients in the case of monochromatic radiation. The main purpose of such measurements is to appraise the characteristics of the radiation under consideration. When the object in view is to obtain data for protection of personnel, the conditions of measurement should be those appropriate to that problem. Let us study by absorption measurements the characteristics of roentgen rays produced at 2.5 million volts, for which data are available in the literature.[7]

A good experimental setup is shown in Figure 9. The provisions for preventing scattered radiation from reaching the chamber are obvious. We may point out, however, that the chamber "sees," and therefore may receive, radiation originating in the doubly cross-hatched volume of the absorber. Hence, the necessity for making D_1 of lead thicker than the largest thickness of lead absorber to be used, by several half-value layers. In practice this type of setup is seldom possible. The room in which the roentgen-ray machine is housed is usually small and the lead shield around the target of insufficient thickness. As a result, a considerable amount of direct and scattered radiation is present in every part of the room. A second diaphragm D_2 of sufficient thickness and size can hardly be provided. The usual procedure is then to place the ionization chamber in a lead sleeve or collimator. This is shown in Figure 10. The lead shield around the target is intended for ordinary use of the machine and allows a wide beam of radiation to pass

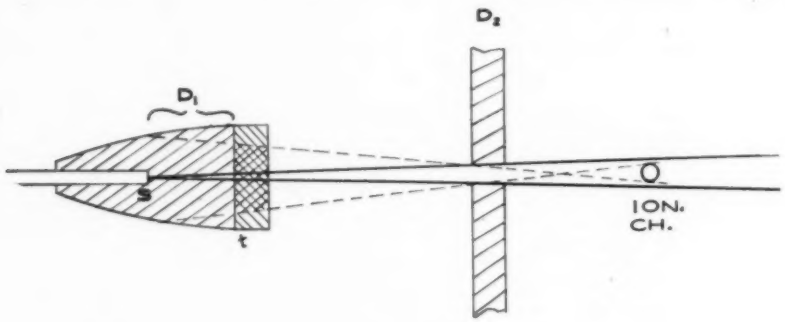

FIG. 9

* In this case the source is usually very weak and one is forced to use Geiger-Müller counters instead of ionization chambers. The wavelength response of these counters presents a much more difficult problem than that of the ionization function of a chamber, discussed here. The subject is of great practical importance but it would take us too far afield to discuss it in the present paper.

† All sources of high energy radiation, with the exception of a few radioactive isotopes, produce polychromatic radiation and there is no practical way of separating it into its monochromatic components.

through. A large portion of the absorber is strongly irradiated and scattered radiation from all this region can reach the ionization chamber, in spite of the lead sleeve. Scattered radiation from the wall can also reach the chamber, but it can be made negligibly small by using a long sleeve. The chief complication, however, is due to scattered and secondary radiation produced in the sleeve itself. This can be greatly reduced by placing over the incidence end of the collimating diaphragm of small aperture at the incidence end. The curve shows a rapid drop at the beginning followed eventually by a straight line. The curvature indicates that the softest components of the beam were gradually eliminated by increasing thicknesses of lead. On the other hand, the straight line portion of the curve does not prove that the radiation, by this process of differential attenuation, finally became monochromatic and in equilibrium with

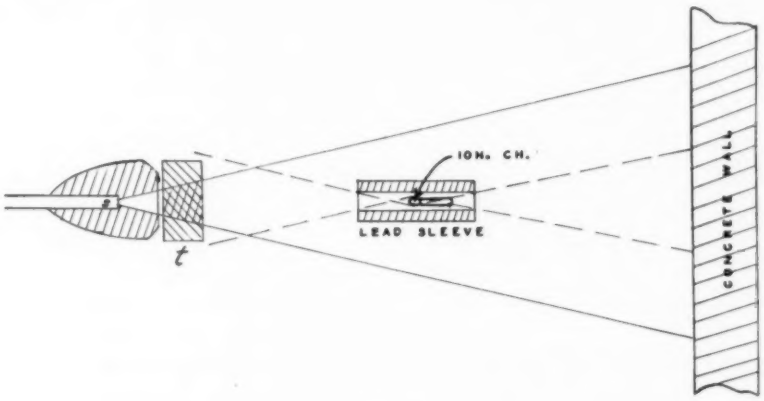

Fig. 10

sleeve a thick lead diaphragm with a small aperture (not shown in Fig. 10). When this second diaphragm is absent, there must be a considerable amount of soft radiation present within the sleeve. The relative amount certainly varies with the wavelength and hence with the thickness of the absorber, at least at first. The significance of the first part of an absorption curve thus obtained is obscured by spurious effects. Fortunately, the interpretation of the first part of the absorption curve of polychromatic radiation is difficult at best and not of great practical importance. Nevertheless, one should strive to avoid complicating factors and thus make results obtained by different investigators more readily comparable.

An absorption curve in lead for a constant voltage of 2,500 kv. is shown in Figure 11, as published by Petrauskas, Van Atta and Myers.[7] It was determined with a "lead sleeve" setup, including, however, a its secondaries, in the range of lead thickness used. That it is not monochromatic radiation of 2,500 kev. may be readily proved by comparing the absorption coefficient derived from the straight portion of the curve with the one for 2,500 kev. (2.5 mev.) given in Figure 5. They are respectively 0.617 and 0.475. Monochromatic radiation with $\mu = 0.617$ has an energy of 1,500 kev. and this might be considered to be the monochromatic equivalent of the radiation beam after traversing several centimeters of lead.

The roentgen-ray spectrum produced by a tube voltage of 2,500 kv. contains very little 2,500 kev. radiation. For purposes of illustration let us assume that in the initial spectrum the photons of 1,500 kev. energy are 8 times as numerous as the 2,500 kev. ones. The half-value layers for the two are 1.12 and 1.46 cm. of lead respectively. A lead thickness of 5 cm. corresponds, therefore, to 4.45 hvl for the softer component

and 3.43 hvl for the harder. Since the difference is practically 1 hvl, the harder component gains over the softer one by a factor of 2 in passing through each 5 cm. of lead. Since the softer component was initially 8 times more intense, it is still 4 times more

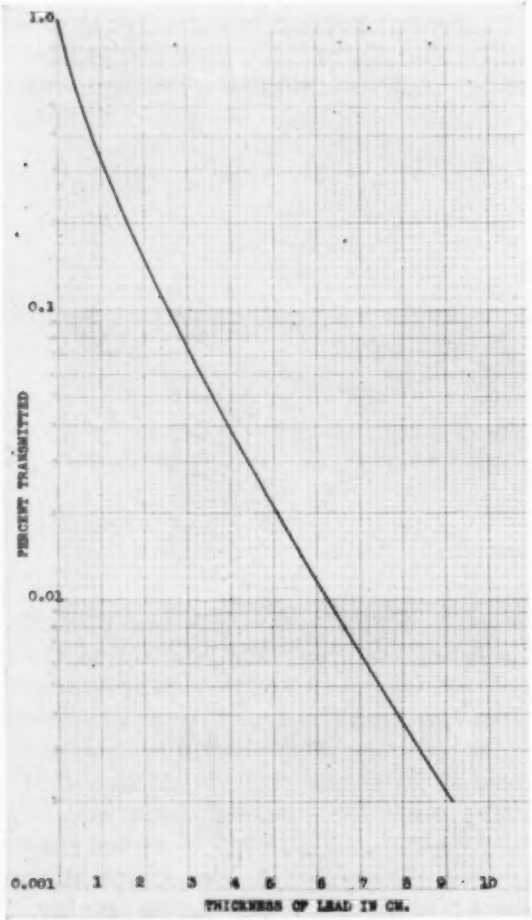

FIG. 11

intense than the harder component after the first 5 cm. To be equal in intensity the two must traverse 15 cm. of lead. This example serves to show, also, that in this energy range elimination of the longer wavelength components takes place quite slowly. Nevertheless, it is clear that eventually the shortest wavelength must prevail, even if its intensity is very low initially. In the end, therefore, the radiation should be monochromatic* and of the shortest wavelength present in the beam. This point in an absorption curve is seldom, if ever, reached in practice in the high voltage region. For one thing the intensity gets too low for accurate measurement. The component of highest energy is very weak especially when pulsating voltage is applied to the roentgen tube. The coefficient of absorption is not very sensitive to changes in wavelength.

The efficacy of differential absorption in lead may be judged by inspection of Figure 5. In this connection it is useful to remember that when the coefficients of absorption (or the half-value layers) for two wavelengths differ by 10 per cent, it takes 10 hvl of the absorber for a differential absorption factor of 2.† For a factor of 4 it takes 20 hvl. Few absorption curves determined by actual measurements extend beyond 10 hvl. We may conclude, therefore, that the radiation is far from monochromatic in spite of the straight line absorption curve.

Mention was made earlier that in the supervoltage region the relation between intensity of radiation and ionization chamber readings is not far from linear. Reference to Figure 7 shows, however, that be-

* In equilibrium with its secondaries.

† To obtain a general relation, let

μ_1 = coefficient of absorption of harder component

μ_2 = coefficient of absorption of softer component

(that is, $\mu_2 > \mu_1$)

$$r = \frac{\mu_1}{\mu_2} = \frac{(\text{hvl})_2}{(\text{hvl})_1}$$

f = differential absorption factor, that is, factor by which i is desired that intensity of harder component be higher than that of softer component.

n_1 = number of half-value layers of the harder component required to bring this about, when both components are of equal intensity initially.

Then

$$n_1 = \frac{3.32\, r \log f}{1 - r}$$

or

$$n_1 = \frac{3.32\, \mu_1 \log f}{\mu_2 - \mu_1} = \frac{3.32\, (\text{hvl})_2 \log f}{(\text{hvl})_1 - (\text{hvl})_1}.$$

The equivalent number, n_2, of half-value layers of the softer component is

$$n_2 = n_1 + 3.32 \log f.$$

In the example

$$\frac{\mu_1}{\mu_2} = r = 0.9 \qquad f = 2 \text{ or } 4$$

$$n_1 = \frac{3.32 \times 0.9 \times \log 2}{1 - 0.9} = 9$$

$$n_2 = n_1 + 1 = 10$$

for $f = 4$ $n_1 = 18$ $n_2 = 20$

tween 1,000 and 2,500 kev. $\tau+\sigma_a$ (for air) varies about 25 per cent. Most of the energy in the 2,500 kv. roentgen-ray beam just considered lies between these limits. As the thickness of lead increases the center of gravity of the energy spectrum shifts towards the 2,500 kev. limit. Therefore, the ionization chamber registers a somewhat smaller fraction of the energy reaching it, as the thickness of lead increases. This tends to make the absorption curve, *plotted as ionization current versus thickness*, straighter than it would be if the ionization function of the chamber remained constant. This effect is probably much less than the 25 per cent extreme mentioned above, in the straight part of the curve of Figure 11. It could very readily amount to that if much greater thicknesses of lead had been used. While on the subject, it may be pointed out that this type of effect is very pronounced in the case of roentgen rays produced at voltages up to about 150 kv. (i.e. less than 100 kev. monochromatic). Inspection of Figure 7 makes this self evident.

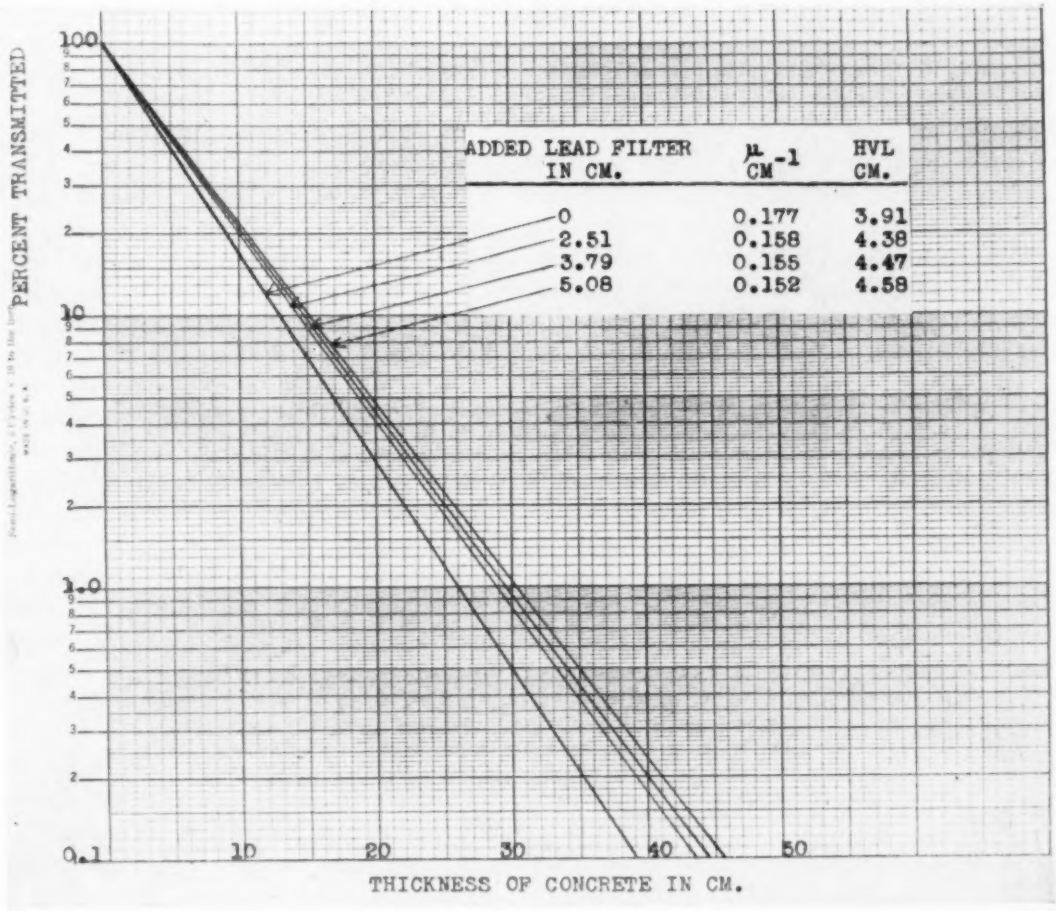

Fig. 12

The interpretation of absorption curves is important in the problem of protection; we may then dwell on the subject a little longer. The curves of Figure 12 were obtained by Folsom and Focht[3] using very well collimated beams, long distances and "air wall" ionization chambers. For 1,000 kv. roentgen rays the ionization function

of the chamber is very nearly constant and it has no influence on the shape of the curves beyond a few centimeters of concrete. The interesting thing is that these curves are straight but the slope depends on the thickness of the lead filter used. The reason why each curve is straight is, of course, that the coefficient of absorption for concrete does not vary much in the wavelength range involved in each curve. Differential absorption of the longer wavelengths is very ineffective—much less effective than in the case of the lead absorption curve previously discussed—and the radiation is not monochromatic. The lead *filter*, however, does change the quality of the beam (as indicated by the different slopes) and it does so without decreasing the intensity of radiation to the vanishing point. Therefore, with greater thickness of concrete all the curves should tend to assume the same slope. This means that, eventually, at least some of the curves must bend upward. They are straight for reasons already given and because the thickness of concrete used was not sufficiently large. Aside from the fact (pointed out by Folsom and Focht) that narrow beam absorption data are not directly applicable to the protection problem, it should be emphasized that the thickness of absorber used (and the filter) should be as large as is apt to be needed for protection barriers.

We shall analyze now the protection problem with the object of determining, if possible, the conditions under which absorption measurements should be made in the laboratory to be most directly applicable. The problem is simply this: We wish to obtain data which will enable us to design in advance all protective barriers needed in a roentgen-ray installation, with the assurance that protection of personnel will be fully adequate but not extravagant. The economical aspect of the problem, of course, assumes greater importance as the use of higher and higher voltage roentgen-ray generators becomes more common. In the lower voltage range the situation is well in hand for three reasons: (1) lead is largely used as protective material and the scattering problem is not serious; (2) measurements made on existing installations provide a check on calculations and the results of the comparison are available for future use; (3) the cost of protection is not high.* It consists largely of labor costs and the use of a thicker lead barrier "to be on the safe side" entails little additional expense.

If the permissible daily dose for continued exposure of the whole body is 0.1 r, it means that radiation of an average dosage rate of 12.5 mr/hr. is present—or at any rate is allowable—in rooms occupied by personnel. This radiation is subject to the same physical laws as radiation of higher dosage rate. It is, therefore, absorbed, scattered and rescattered in the room. If then, the *total* dosage rate to which an individual is exposed cannot exceed 12.5 mr per hour, the dosage rate of the radiation *entering* the room must be lower. How much lower? Also, and more important, how can we calculate the dosage rate of the radiation entering the room? The answers to these questions (and others) must be known before we can design protective barriers that are not only sufficient but economical.

In Figure 13 the source of high voltage roentgen rays (say, 2,000 kv.) is shown in one room, an ionization chamber in an adjoining room separated from the former by a thick concrete wall. The radial lines indicate the directions from which the chamber receives radiation, no attempt being made to represent the magnitudes of the different components. The heavy lines proceeding from the source to the chamber indicate the "narrow" beam that might be used in the making of measurements of the type previously discussed. If such measurements were actually made in the room shown, it would be found that the unrestricted beam reading would be several times higher than the one obtained

* The cost relative to the price of the machine is, nevertheless, high.

with the collimated narrow beam. The distinction between absorption measurements intended for absorption coefficient determinations and those applicable to protection problems is not, therefore, a mere refinement.

Inasmuch as the laws of interaction of radiation and matter have been worked out quite satisfactorily, in principle one could calculate the dosage rate at different points in the room, having first ascertained the characteristics of the radiation by appropriate narrow beam measurements. The necessary reduction factor in dosage rate that the barrier must bring about is so great, however, that the radiation undergoes many repeated changes in wavelength and direction in its passage through the barrier. Thus the mathematical problem becomes too involved and simplifying assumptions are introduced to bring it into manageable form. This reduces the reliability of the results to an extent that is difficult to estimate.

A second method by which the necessary data may be obtained is by interpolation and extrapolation making use of existing installations. Thus one could calculate the dosage rate on the basis of absorption coefficients, then make actual measurements at the point in question and determine the correction factor to apply to the calculated value. By doing this under many different conditions, certain empirical relations could be obtained which could be applied to the design of new installations. In making use of this method care should be exercised not to extrapolate too far. That is, the conditions of the new installation should not be too far removed from those on which the empirical relations are based. While this scheme is feasible, it is actually a matter of considerable difficulty to obtain the necessary experimental information. Aside from geographical limitations, existing supervoltage installations are so constructed that seldom can one obtain the desired data without objectionable complicating factors. Nevertheless more work of this sort should be done. After all, it is only by making careful measurements after the installation has been completed that the accuracy of the calculations can be checked.

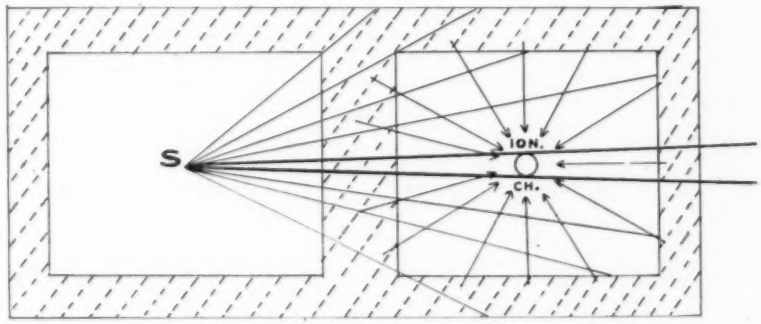

Fig. 13

One difficulty with the "correction factor" method just discussed deserves mention. The simplest way in which to apply this method would be to use the absorption curve for the radiation and material under consideration, and to determine therefrom the minimum thickness of the barrier. Then the thickness would be increased by an amount determined by the appropriate empirical correction factor. This procedure relies heavily on the absorption curve, which, as we have seen, is influenced by the experimental setup. For one thing the cross-section of the beam used is very important.* What constitutes a "narrow" beam has been largely a matter of personal

* See, for instance, Folsom and Focht's paper already referred to.

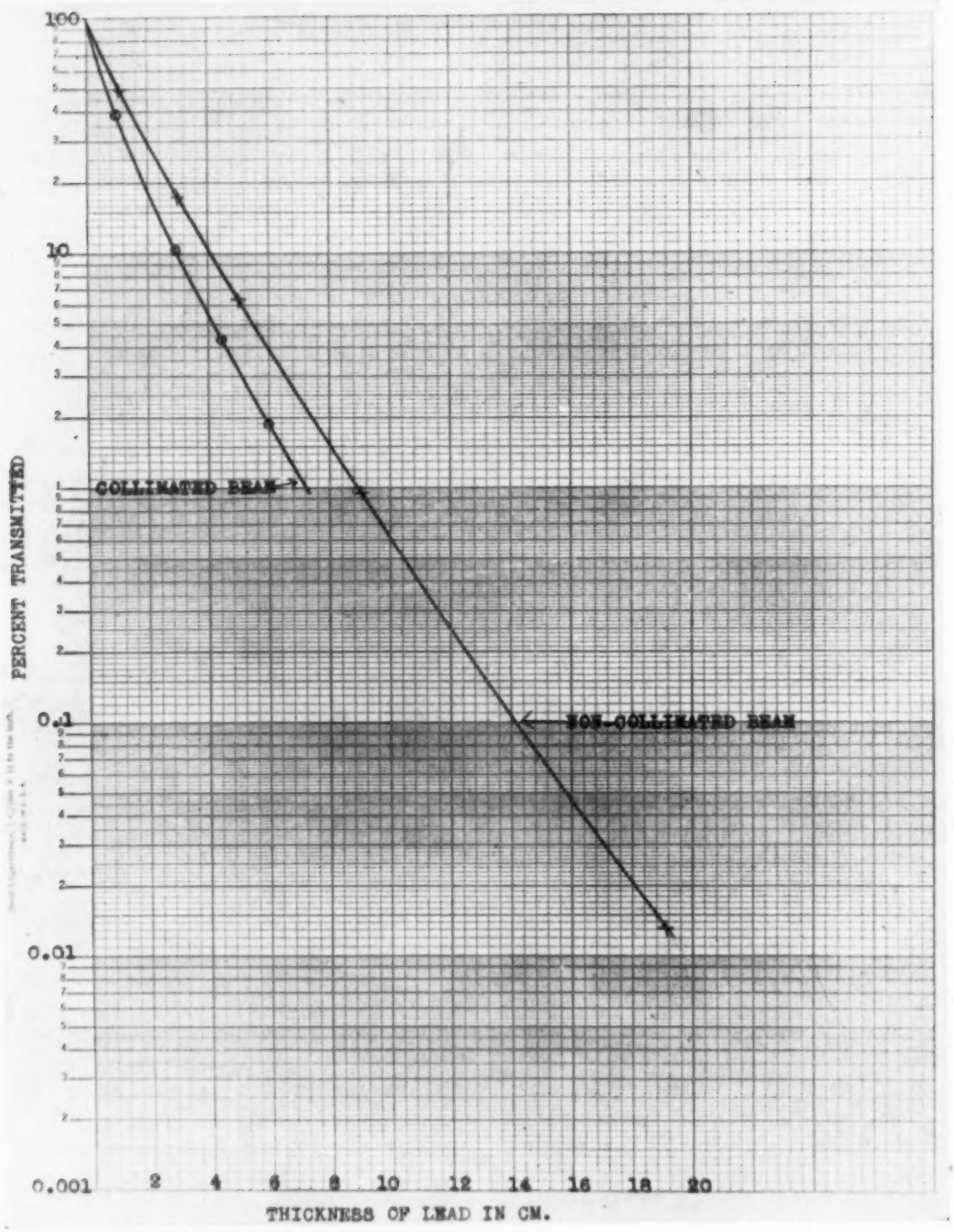

FIG. 14

opinion in the past. Very narrow beams are difficult to use and one tends to compromise. Therefore, the calculated minimum thickness referred to above is subject to considerable variations, depending on the choice of experimental setup, and in particular on the size of beam and on the initial filter used. It should be remembered

that a certain percentage difference in the coefficients of absorption (slopes of the curves) makes the same percentage difference in the *total* thickness of the barrier. On the other hand, a small percentage difference in the absorption coefficients makes a large difference in the dosage rates of the radiation transmitted through a thick barrier. For example, a 15 hvl concrete barrier would be either ($15\times3.91=$) 58.7 or ($15\times4.58=$) 68.7 cm. thick depending on which one of the two extreme curves in Figure 12 is chosen. If the steeper curve is chosen ($\mu=0.177$) but the radiation actually behaves as if the coefficient of absorption were 0.152 (17 per cent difference in μ), the dosage rate of the radiation transmitted through 58.7 cm. of concrete would be 4.27 times higher.*

In view of the numerous difficulties encountered in the determination of narrow beam absorption curves in the supervoltage region, it is desirable to find a more practical scheme. It is clear that some sort of absorption curve is necessary. Preferably we should have one that is not so sensitive to differences in experimental setup. If we place the absorbing material completely around the ionization chamber, we avoid many difficulties. We also obtain an absorption curve that represents the conditions of the protection problem more closely than the narrow beam curve determined in the customary way. The ionization chamber might be said to represent a miniature room surrounded by walls of the protective material. There are at present no absorption curves obtained in this way and comparison with conventional absorption curves is impossible. It is not difficult to predict, however, that the slope of such a curve would be less than that of its narrow beam counterpart. Using this more representative type of absorption curve to determine the thickness of the desired barrier, we are bound to get a closer approximation to the correct thickness. The correction factors, which in any event must be determined empirically, will then be much smaller.

We may examine for a moment an absorption curve obtained by a method that in some respects resembles the one suggested above. The curve was obtained by Braestrup† by *surrounding the source* (radium) with lead cylinders of increasing thickness. For comparison Figure 14 contains, also, an absorption curve obtained with a well collimated gamma-ray beam. The same spherical ionization chambers were used in both cases and they were never closer to the radium than 1 meter. The difference between the two curves is not due to radiation scattered by the walls of the room and objects in it. It is almost entirely due to radiation scattered by the mass of lead around the source. When the absorber is placed around the chamber a similar situation exists in that much of the radiation scattered in the material reaches the chamber. In the case of the gamma rays of radium it is interesting to note that it makes little difference whether the lead is placed around the source *or* around the chamber, at least up to a thickness of 4 cm. as may be seen from Table 1.‡

Table I

Thickness of Lead Shield cm.	Relative Ionization with	
	Lead shield around radium	Lead shield around chamber
0	100.0	100.0
0.32	75.0	82.5
2.0	32.1	34.0
4.0	11.6	12.4

Roentgen radiation in the energy range

* This figure may be obtained readily in two ways: The correct thickness for $\mu=0.152$ is 68.7 cm. Therefore, the barrier is thinner than it should be by 10 cm., which is equivalent to $\frac{10}{4.58}=2.18$ hvl. Hence by reference to scales $A-B$ of Figure 1 the dosage rate is 4.27 times higher. Or use may be made of the relation given in the footnote on p. 570, in which case $r=0.86$, $n=12.8\left(\text{that is, }\frac{58.7}{4.58}\right)$ and solving the equation $f=4.27$.

† Personal communication.

‡ I am indebted to Dr. E. H. Quimby for these measurements.

in which pair formation is important is produced at present by generators of the "betatron" type,[5,8] operating at maximum electron energies of a few million to 100 million electron volts. When electrons with this energy impinge on a target, they produce polychromatic roentgen rays. Just as at lower voltages the energy of the most energetic photons is equal to that of the impinging electrons and the bulk of the radiation is of much lower energy—about one-half or two-thirds of the maximum. It is desirable, therefore, to obtain absorption curves for the purpose of studying the interaction of radiation and matter in this new range, and for protection purposes. As already explained, the experimental conditions must be adjusted to the purpose.

In the range of 20 to 100 million volt roentgen rays the protection problem is greatly simplified by the fact that most of the radiation is emitted within a very narrow cone with its axis in the direction of travel of the electrons at the time of impact. For 20 and 100 million volt roentgen rays the vertex angle of this cone is approximately 9 and 2 degrees, respectively. Radiation emitted at 90° to this axis is not only much less intense but also much softer. Accordingly, if the beam of radiation is fixed in position or is adjustable to a limited degree, *thick* protective barriers are needed only in certain directions. There is, also, a second favorable element in that substances of high atomic number become increasingly more effective as absorbers as the voltage increases beyond the point at which pair formation sets in. As previously mentioned lead is most transparent to 3 to 4 mev. roentgen rays. It attenuates 20 mev. roentgen rays at the same rate that it attenuates 1 mev. roentgen rays (see Fig. 5). With 100 mv. roentgen rays lead behaves as a filter but in the opposite direction to that with which we are familiar in the low voltage range. It tends to *increase* the average wavelength of the transmitted radiation up to that corresponding to 3 or 4 mev. In the case of concrete, which is commonly used in the supervoltage range, the situation is less favorable because pair formation in this material is less and does not become very prominent until photon energies of the order of 10 mev. are reached. Also, the coefficient of absorption of concrete increases very slowly beyond 10 mev. This applies to all substances of low or medium atomic number, and therefore concrete and lead are still the most practical materials to use for protective barriers in the energy range above 10 mev.*

The measurement of multimillion† volt roentgen rays for protection purposes involves the fundamental question of the biological effectiveness of such roentgen rays. While little is known from actual experience, it may be assumed with confidence that a certain amount of (ionization) energy actually absorbed by a living cell will produce the same biological changes, whether the energy is imparted to the cell by supervoltage or multimillion volt roentgen rays—provided all other conditions are the same. The latter statement is not intended as a "tricky" reservation. Thus, obviously, the distribution of absorbed energy throughout the biological object and the time factors must be the same in order to make any valid comparison at all.

The distribution of the ionization produced in the human body will be quite different in the case of multimillion volt roentgen rays for three reasons: (1) the radiation is more penetrating; (2) more

* High energy photons cause nuclear reactions resulting in the production of radioactive isotopes, which emit ionizing radiations. The choice of material for a protective barrier may be influenced to some extent by this consideration. The radioactive isotopes produced in the barrier (or other object in the path of the roentgen rays) would emit radiation continuously even when the generator is shut down. Fortunately, the efficiency of production of radioactive isotopes is very low and in general this is not a serious complication in the energy range attained thus far (20 to 100 mv.).

† This term is not very good but it fills the need for a simple expression to use in referring to roentgen rays produced at voltages of several million volts and over. The term "supervoltage," which has found wide acceptance might well be limited to the range of 1 or 2 million volts. A distinction should be made between the energy range in which the Compton process of absorption predominates and the one in which pair formation becomes important.

important than this, when the beam initially is devoid of "secondaries" the depth dose is actually much higher than the skin dose, at depths of the order of several centimeters;[5] (3) since the probability of pair formation increases with the square of the atomic number,[4] tissues such as bone, containing fairly high atomic number elements, will absorb more energy than other tissues in a radiation field of equal intensity. If the tissue dose is measured properly,[1] in the region or regions in which the biological effect originates and develops, these physical differences can be taken into account, and the biological changes to be expected may be predicted. We shall discuss this matter only briefly and so far as it concerns the present problem.

In making protection measurements one must take into account the unusual distribution of absorbed energy in the human body just mentioned. At what depth in the soft tissues of the body the maximum energy absorption occurs depends on the photon energy of the radiation and on its "equilibrium status."* The importance of the latter was demonstrated first in the case of the gamma rays of radium,[2] in which energy range it begins to be appreciable. In the case of multi-million volt roentgen rays it is incomparably more marked. The layer of tissue through which the radiation must pass to be in equilibrium with the secondary electrons is approximately 3.5 cm. in the case of 20 mv. roentgen rays[5] and may reach 9 or 10 cm.† at 100 mv. The difference between the dose at the surface of the skin and that at the depth at which it is highest, may be very large, depending on how completely "stripped" of secondary electrons the roentgen-ray beam is when it reaches the skin. It is obvious that for protection purposes we are interested in this maximum depth dose. To get a reasonably close approximation of its value the ionization chamber must be surrounded by a thickness of tissue equivalent material equal to the equilibrium thickness. This varies with the energy of the radiation and must be determined experimentally. It also varies with the equilibrium status of the radiation. Because of the large thickness needed at very high voltages (say 100 mv.) the absorption of radiation in this layer is considerable. Hence, if the radiation is already in equilibrium with its secondaries, an ionization chamber surrounded by the equilibrium layer will read lower than it should to represent the radiation that (some internal organs of) the human body would receive. It is best to determine the equilibrium status of the radiation at the time and place of measurement by gradually increasing the thickness of material surrounding the chamber. (A sharp maximum in the ionization reading should not be expected.)

It might be mentioned in this connection that the equilibrium status depends on the nature of the material traversed by the radiation. One hundred million volt roentgen rays passing through a very large thickness of lead would be in equilibrium with the secondaries so far as lead is concerned, but not with respect to the tissue equivalent material surrounding the ionization chamber. This is because the pair formation process depends on the square of the atomic number. The same thing applies to concrete but to a much smaller extent. A narrow beam of 100 mv. roentgen rays passing through a thick concrete wall is not in equilibrium with its secondaries at a considerable distance beyond the wall, for another reason: the secondaries tend to be scattered out of the narrow beam.

* By "equilibrium status" is meant the extent to which "secondaries" are present. "Secondaries" is a loose term referring to electrons, positrons, scattered radiation, annihilation radiation, etc. The thickness of matter through which the radiation must pass to be in equilibrium with its secondaries depends, among other things, on what secondaries we are interested in. If we consider only electrons, the equilibrium thickness is much less than when secondary photons are included. The thickness also depends on the geometry of the beam and absorber (parallel or divergent rays, extent of absorbing mass, etc.).

† This thickness is governed largely by the maximum range of the secondary electrons produced in the absorber, and to some extent by the experimental conditions. At very high energies electrons lose much energy in "lumps" by radiative processes and the range is shorter than it would be otherwise.

Assuming that measurements are made with an air wall ionization chamber surrounded by the proper equilibrium layer, we may express them in "roentgens," in spite of some complications that need not be discussed at this time. The question now arises as to whether the permissible daily dose of 0.1 r applies to multimillion volt roentgen rays as well. In the range of ordinary and supervoltage roentgen rays, deep-seated organs always receive less radiation than the surface layers of tissue. In the case under discussion the opposite situation is apt to exist. Therefore, even when measurements are made in such a way that they represent the maximum depth dose, for the same number of roentgens as measured, the internal organs are apt to receive considerably more radiation in the case of multimillion volt roentgen rays than in the case of ordinary roentgen rays. To be on the safe side and until sufficient practical experience has accumulated, it is suggested that a safety factor of 2 be introduced to compensate for the larger amount of radiation reaching the internal organs. Unfortunately this is not all.

Mention has been made of the differentially high absorption by bone when the pair formation process is prominent. This effect, which is favorable from the point of view of treatment of bone tumors, increases the danger of exposure to radiation. As stated previously, in the pair formation process, the photon imparts all its energy to the electron and positron together. That in excess of the minimum required to produce the pair (1,022 kev.) appears as kinetic energy of the particles. When the photon energy is, let us say, 21 mev. and the kinetic energy is shared equally, the electron and the positron will be endowed with a kinetic energy of 10 mev. each. The range of these particles in tissue is a few centimeters and the energy of those originating in bone is not all dissipated *in situ* in the bone. In particular a good proportion will be absorbed by the marrow. Similarly the Compton process is more marked in bone, in proportion to the higher electron density in bone, and the secondary electrons produced within it can also reach the marrow. Since the effect of radiation on bone marrow is the chief limiting factor when the entire body is exposed to hard roentgen rays, the process just described increases the radiation hazard in the case of multimillion volt roentgen rays. The magnitude of the differential increase in bone marrow dose depends on the photon energy of the radiation, and therefore the allowance to be made in the permissible daily dose varies (i.e. increases) with the voltage* at which the roentgen rays are produced. In the absence of experimental data bearing on this point, the allowance which should be made can be only a rough estimate. As such it is suggested that the permissible daily dose be reduced by a factor of 2 or 3 in the case of 100 mv. betatrons. Combining this with the factor of 2 previously mentioned we arrive at an estimated permissible daily dose of 0.02 r for exposure of the whole body to 100 mv.† roentgen rays. A more reliable value may be obtained by properly conducted measurements, in which the physical conditions existing in the human body are simulated closely.‡

In the multimillion volt range of roentgen rays, only closed ionization chambers can be used. The purpose for which the measurements are intended determines the design of the chamber. For protection measurements it was mentioned before that the chamber should be surrounded by a tissue equivalent material of such thickness as will give the maximum ionization current reading. For 100 mv. roentgen rays this thickness is of the order of 10 cm. Even if the air space of the chamber is

* This terminology is not quite applicable to betatrons since the voltage at which the machine is rated is nowhere present. In effect, however, the electrons are imparted that amount of energy that they would acquire in the conventional type of roentgen tube operating at the stated betatron voltage.

† Note that this is not meant to be mev.

‡ A word of caution is in order in regard to animal experiments intended to provide protection data. The distribution of radiation in the body of small animals will be quite different from that in man. This, of course, is also true in the case of ordinary roentgen rays, but the difference is on the safe side.

1 cm. in diameter, the outside diameter of the thick chamber "wall" will be more than 20 cm. The roentgen rays, however, are confined mostly in a narrow cone, and the intensity varies considerably with the angle of emission even within this narrow cone. In order to obtain a reasonably uniform distribution of radiation over a 20 cm. circle the chamber must be placed at a distance of 8 or more meters from the source. If we wish to obtain an absorption curve by surrounding the ionization chamber with different thicknesses of the absorber up to the large values needed for protection, the distance at which the measurements could be made becomes entirely impractical. Fortunately, at very high energies secondary electrons, photons and positrons are emitted largely in the forward direction. Consequently, material not directly in front of the chamber should contribute relatively little to the ionization reading. This (like many other interesting problems in this new roentgen-ray range) can be settled only by experiment. It is important, therefore, that at least in some multimillion volt installations provisions be made to permit making measurements at long distances from the source.

The measurement of multimillion volt roentgen rays in roentgens presents certain difficulties that must be ironed out by future experiments. The present definition of the unit is: "The roentgen shall be the quantity of roentgen or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air, produces, in air, ions carrying 1 esu of quantity of electricity of either sign." The "associated corpuscular emission" refers to the secondary electrons in the case of ordinary roentgen rays. When pair formation occurs, the electron and positron of the pair also constitute corpuscular emission and must be included. To measure roentgen rays in roentgens we much collect all the ions produced in air by all the corpuscles liberated in 0.001293 gram of air. The number of such ions is proportional to $\tau+\sigma_a$ in the range of ordinary roentgen rays. In the case of multimillion volt roentgen rays it is proportional to $\sigma_a+\sigma_p$, since τ is negligible in this range. The very large range of the secondary particles precludes the use of the standard parallel plate ionization chamber. Therefore, a closed chamber must be used. In principle the requirements which the chamber must fulfill are the same as in the case of ordinary roentgen rays. That is, the conditions must be such that the ionization produced in the air volume is equal to that which would be produced in air by complete absorption of all the particles liberated in the mass of air within the chamber. In practice this is brought about by making the chamber walls of an air equivalent material of a thickness equal to the range of the fastest secondary particle. As we have seen, this means a wall thickness of many centimeters in the range of 100 mv. roentgen rays. In this large mass secondary, tertiary, etc., photons are produced which then contribute to the "corpuscular emission" in the chamber, but according to the definition of the roentgen this contribution should not be included. There is also a theoretical complication. When the definition was adopted it was not contemplated that roentgen rays of the near-cosmic ray type would be available for practical uses. It was then assumed that essentially all the energy imparted to the "corpuscles" (i.e. electrons) would be used up in producing ions. In the very high energy range electrons lose considerable energy by radiative processes producing photons. Furthermore, when a pair is created the photon disappears, and therefore all its energy is transferred to corpuscles and should be included in the measurement. Of this energy 1,022 kev. is needed just to create the electron and positron. That in excess of this amount is available to produce ions and is measured (except for the portion that may be transferred to photons as mentioned above and the amount that may be retained by the positron when annihilation occurs before it comes to rest). The 1,022 kev. (or larger) portion is imparted

to photons when the positron is annihilated. While it should be registered in the measurement, this energy is not immediately available to produce ions. This effect is appreciable in the relatively low energy range of several mev. because 1,022 kev. is then a substantial fraction of the total energy imparted to the pair. The difficulty will have to be resolved by agreement at some future International Congress of Radiology.

Referring back to Figure 7 it may be pointed out that if the conditions of measurement meet the requirements of the present definition of the roentgen, the ionization current readings will be very nearly proportional to the roentgen-ray energy flux in the region of 8 to 300 mev. The dotted portion of the curve in Figure 7 represents the sum of σ_a and σ_p, which is 2×10^{-5} cm.$^{-1}$ at 8 or 9 mev. and remains nearly at this value up to about 300 mev.

Before closing, it is desirable to point out that the mathematical part of protection problems in the multimillion volt range may be solved by the same methods developed in Part 2 of this paper.* However, it should be remembered that equation (1) is based on a permissible daily dose of 0.1 r. This is higher by a factor of 2 or more than the value applicable to the very high energy range. The charts derived from equation (1) may be used, but one or more half-value layers must be added to the number determined thereby, depending on the appropriate value of the permissible daily dose.

SUMMARY

Solution of Protection Problems in Terms of the Half-Value Layer. The accepted permissible daily dose of roentgen rays for long continued exposure of the whole body is 0.1 r. For an eight hour working day this corresponds to a dosage rate of 12.5 milliroentgens per hour (12.5 mr/hr.). Given a roentgen-ray machine with a certain output and quality of radiation, the protection problem consists of determining the thicknesses of absorbing barriers to be placed around the source in order to reduce the dosage rate to 12.5 mr/hr. in all regularly occupied regions.

If the dosage rate at a given point is 1 r/min., it may be reduced to ½ r/min. by interposing a protective barrier of any material of thickness equal to one half-value layer (1 hvl). Addition of another half-value layer reduces the dosage rate to ¼ r/min., and so on. In this way it is found that to reduce the dosage rate to 12.5 mr/hr. a barrier of 12.2 half-value layers be interposed between the source and the point in question. If the initial dosage rate is 2 r/min. instead of 1 r/min. one additional half-value layer is required; if 4 r/min. 2 additional half-value layers are needed, and so on. On the other hand, at a point twice as far from the source, the initial dosage rate will be ¼ r/min. instead of 1 r/min. and the thickness of the barrier may be decreased by 2 half-value layers. If the distance is doubled again 2 more half-value layers may be subtracted, and so forth. It follows, therefore, that both the radiation output and distance factors of a problem may be expressed in terms of the corresponding number of half-value layers to be added or subtracted. The problem is then reduced to one of algebraic addition instead of multiplication and division. This makes possible the construction of simple graphical charts for the solution of practical problems. Figure 2 in the text is the most useful one.†

Having determined (by means of Fig. 2) the number of half-value layers required in the barrier to reduce the dosage rate at a given point to 12.5 mr/hr., it is necessary to translate it into actual thickness of the material to be used. This requires an absorption curve for the radiation and the material under consideration. If the curve, plotted to a semilogarithmic scale, is a straight line, the half-value layer is constant throughout the thickness range and its value may be derived readily from the curve. The thickness of the barrier is

* While the emitted radiation is confined largely within a narrow cone, the inverse square law still holds.

† Large blueprints of this chart may be obtained from the author at cost.

obtained by multiplying the number of half-value layers required by the thickness of the half-value layer. If the absorption curve is not straight a different procedure (explained in the text) must be followed. It should be noted that the fundamental data embodied in the absorption curve are necessary for the solution of protection problems, no matter what method is used.

Discussion of Absorption Curves. Physicists are interested primarily in the laws that govern the interaction of radiation and matter. To study the different processes of interaction, absorption curves are determined under appropriate conditions. In general, these conditions do not fulfill the special requirements of the protection problem and such curves should not be used for this purpose. The discrepancy becomes more marked at the higher voltages (1 million and over) which are coming into prominent use in medicine and industry. In this voltage range the factor of uncertainty at present is too large to permit the design of barriers that provide adequate protection *at minimum cost.*

Practical limitations make it very difficult to duplicate in the laboratory the numerous and varied conditions obtaining in high voltage installations. Nor would it be desirable to do so. It is preferable to obtain basic experimental data that can be applied most directly to protection problems in general, taking care of special conditions by suitable allowances. The basic data should be such that these allowances will be small and will introduce little uncertainty in the final result. It is suggested that absorption curves determined by placing the absorber completely around a properly designed "air-wall" ionization chamber, would serve this purpose best. Such curves are not apt to be influenced markedly by the experimental setup and can be determined readily in any laboratory.

Some Protection Problems Peculiar to Multimillion Volt Roentgen Rays. The expression "multimillion volt roentgen rays" is suggested—with some reluctance—to denote the energy range in which absorption by the pair formation process plays an important part. Depending on the material under consideration, this range extends from a few million volts up.

In this case the protection problem is simplified by the fact that the emitted roentgen rays are confined largely within a narrow cone and that all processes of interaction *tend* to maintain the energy in the "forward direction."

In this energy range, lead becomes again a very efficient absorber. Concrete is relatively less efficient than lead but more practical for large barriers.

The measurement of these roentgen rays and the determination of absorption curves present special problems which have not been solved. The conditions under which measurements are to be made to conform with the requirements of the present definition of the roentgen should be agreed upon.

With multimillion volt roentgen rays the distribution of radiation in the human body is quite different from that produced by ordinary roentgen rays. The "depth" dose for a single beam may be many times higher than the skin dose. The ionization produced in a tissue (or energy absorbed) depends also on the presence of elements of high atomic number not only in the tissue and at the point in question but in tissues at a considerable distance. This is because the pair formation process depends on the square of the atomic number and the ranges of the resulting electron and positron may be a few centimeters.

Because of the relatively larger amount of radiation reaching the blood forming organs and the excess of ionizing particles reaching the bone marrow from the higher differential pair formation in bone, the permissible daily dose for exposure of the whole body to multimillion volt roentgen rays should be considerably lower than 0.1 roentgen.

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EXPERIENCES WITH THE ROENTGEN-RAY TUBE

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THE fifty year period commemorated by this number of THE AMERICAN JOURNAL OF ROENTGENOLOGY AND RADIUM THERAPY began during my senior year as an electrical engineering student at the Massachusetts Institute of Technology. The announcement of Röntgen's great discovery was soon followed by intensive work by several members of the teaching staff at the Massachusetts Institute of Technology on various forms of high tension generators to operate the tube. This work was done in collaboration with Dr. Francis H. Williams of Boston, one of the earliest of the pioneers in the application of roentgen rays in the medical field, and it was my exciting privilege to witness many of these developments.

In addition to this, I spent many evenings with a friend who had a large static machine from which various roentgen-ray tubes were operated, and later built a static machine of my own for the same purpose.

I became acquainted very early with the destructive effect of roentgen rays upon living tissue. In fact, it was only a few months after the announcement of Röntgen's discovery that I required medical care for a roentgen burn covering most of the back of one hand.

Meeting with Röntgen

In 1898, while a student in the University of Leipzig, I was greatly thrilled one day when Professor Röntgen entered the room in which I was working on my thesis. The Herr Geheimrath Gustav Weidemann had recently died and Röntgen had been called to take his place as head of the physics department. The impression which I received was an unforgettable one, the more so as I had previously pictured Röntgen as a frail and sickly looking individual rather than the robust specimen I then saw before me who was so tall that he could just enter the door without stooping.

The new Physics Institute in Leipzig had just been completed and the living quarters of the Röntgens would have been on the top floor; but the front windows overlooked the cemetery, and I heard that this view proved unacceptable to Mrs. Röntgen. Be that as it may, the call to Leipzig was not accepted.

Roentgen Tube as Vacuum Furnace

In 1905, when I left the Massachusetts Institute of Technology and joined the staff of the Research Laboratory in Schenectady, I found there an urgent need for a vacuum furnace for melting refractory metals, including tungsten, which were being studied in the hope of finding something better than carbon for the filament of the incandescent lamp. My early experience with roentgen-ray tubes naturally suggested that any material placed at the focus of the cathode rays in such a tube could be either melted or vaporized and, because of the vacuum, without contamination from the atmosphere. So I returned to the Massachusetts Institute of Technology and for several weeks, with the help of a large Heinz induction coil and other equipment kindly lent me by the physics department, I had the experience of working on the development of roentgen tubes in which, for the first time perhaps, one wanted the targets to melt. For these experiments I did not get beyond the stage of using graphite targets. This was perhaps fortunate for me, as graphite, with its low atomic number, is a very inefficient source of roentgen rays, and I was using much energy in the tubes and did not have adequate means of protection. In fact, when Dr. Francis Williams visited me to acquaint himself with the roentgen-ray output of one of the tubes, he said, upon

leaving, that in all his experience he had never before been so much exposed to the rays.

Tungsten Target Development

In Schenectady, when, after several years' work on tungsten, we had succeeded in making that originally brittle metal ductile and had learned how to make good lamp filaments from it, we looked for other applications.

One of the first of these was as a substitute for platinum in the target of the roentgen tube.

Experiments were needed not only to determine design features but also to learn the best metallurgical characteristics of the tungsten metal for the target face. To facilitate the experiments the most powerful roentgen generator of that time, a 10 kw. Snook transformer machine, was acquired. As the purpose of the study was the development of as robust a target as possible, the experiments involved serious overloading of the tubes. This overloading developed weaknesses in this type of tube, which manifested themselves in the form of punctures in the glass envelopes and in cracks due to local overheating. These troubles were subsequently reduced by operating the tubes immersed in oil, but new limitations then presented themselves. With the heavier loads which could be used with oil immersion the aluminum cathodes melted. Then there was the ever-present difficulty of controlling the gas pressure in the tubes.

Experiments Leading to the Development of the Hot Cathode High Vacuum Tube

To avoid the melting of the aluminum cathodes, we tried replacing them with tungsten. This resulted in a tube which was hopelessly unstable ("cranky" in the language of the time).

In another tube, the target and cathode were both made of massive tungsten and identical in form. This tube also was very unstable. The cathode showed essentially the same heating as the target, and the positive ions which bombarded it were about as sharply focused as were the electrons striking the target. It was at first impossible to operate it for more than an instant at a time as, with the application of high voltage, the gas would immediately clean up. It later developed, however, that if the gas pressure were then quickly increased by means of the regulator, the tube could again be operated for an instant, and that if this procedure were repeated several times in quick succession the cathode would become very hot and, in this condition, the tube could be operated continuously. This seemed to bespeak interesting possibilities for a tube in which the cathode could readily be heated at will. The idea of getting electrons from a hot body was not new. Edison had observed it in the incandescent lamp, and O. W. Richardson had investigated the relation between electron emission and temperature. There was, however, much skepticism among physicists at the time as to whether electron emission would continue in case the gas were completely removed from the hot body.

At just the time, however, when we had become conscious of the fact that most of the limitations of the original type of roentgen tube were due to the gas content, without which it could not operate, and were wishing for a stable source of electrons in a high vacuum, Dr. Irving Langmuir in our laboratory was studying electron emission from hot tungsten filaments and finding that even in the highest vacuum the emission was stable and reproducible and that it was even favored in amount by freeing the cathode filament of its original gas content.

These circumstances led me to the construction of experimental high vacuum tubes with a heated tungsten filament as cathode and a tungsten disc as anode. Until these tubes had been continuously pumped for many hours by an exhaust system which was good at the time, but which would now be considered very slow, they showed some of the green fluorescence

of the glass which had always attended the operation of a roentgen tube; but as the electrodes became freed of gas this fluorescence became less and finally disappeared completely. The tube was then stable and controllable, and we were able to satisfy ourselves that its behavior was the same as it would be even if it had a perfect vacuum. The positive ions, essential to the operation of the earlier tubes, were no longer needed and the limitations, most of which were due to the presence of those positive ions, were gone with them.

First Public Demonstration of the New Tube

Dr. Lewis Gregory Cole in New York was the first roentgenologist to have his office equipped with the new type of tube. To introduce it and me to the medical profession, he gave a dinner in New York on December 27, 1913, to which he had invited many prominent roentgenologists. A powerful high voltage generator had been installed in the dining room by Dr. Harry Waite, of the firm of Waite and Bartlett, and with it I was privileged to demonstrate the new tube. On thinking of it now, it seems surprising that the audience stayed through the demonstration. Up to that time the capacity of high voltage roentgen-ray generators had been considerably in excess of what the tubes could stand for any length of time, but with one of the new tubes having a sufficiently large focal spot this was no longer true. I opened the machine up wide and, with the limited amount of protection which the open lead-glass bowl of that time afforded, the audience must have received much more roentgen radiation than they were accustomed to.

Assistance from the Medical Profession

Drs. Lewis Gregory Cole, James T. Case, Walter Dodd, Eugene Caldwell, George E. Pfahler, Preston M. Hickey, and many other roentgenologists, were very helpful to us in those early days in adapting the new tube to the various medical applications.

Mystery Connected with Roentgenography

The gas-filled roentgen tube had not been easy to control and its successful use had called for both patience and experience. It was probably due to the idiosyncrasies of that type of tube that it was not uncommon to hear an expert roentgenologist say that once upon a time he had made a wonderful roentgenogram whose quality he had never since been able to equal. There seemed to be some mystery connected with this—possibly some particular roentgen-ray spectrum was most desirable.

A factor which had contributed to the difficulty of clearing up the mystery was the run-away tendency of the discharge through the gas-filled tube. This had made it necessary that the high voltage source employed should not have good regulation—that is, that for any given setting of the controls, its voltage should fall rapidly with the milliamperage drawn by the tube.

As a result, it had always been very difficult to know what voltage had been effective in producing a given roentgenogram. As ordinarily used, the parallel spark-gap indicated the voltage required to initiate the discharge, but this was usually quite different from, and appreciably higher than, the voltage across the tube when it was later carrying current and so producing roentgen rays.

With the new stable tube, in which the starting and running voltages were the same, we found it desirable to use a high voltage source which did not have a falling voltage characteristic, but instead had good regulation. It was then possible to know in advance what both the milliamperage and the voltage were going to be.

Another factor which must have played some rôle in creating the mystery was the size of focal spot. In a gas tube this was not constant but could vary appreciably with the pressure even during an exposure. Not only this, but as the pressure changed, the position of the focal spot could change also.

There was at the time but little knowledge concerning the matter of focal spot

size. It was quite common for the manufacturer to receive an order for a tube with "pin-point focus." Such a tube, had it been delivered, would of course have been unsatisfactory because of the energy limitation which this would have imposed. This limited knowledge concerning the size of focal spot was such a handicap in the art that for some time after beginning the sale of the hot cathode tube, for educational purposes we supplied with each one a natural size roentgen-ray pinhole camera picture of its focal spot.

Solution of the Mystery

With the hot-cathode tube, in which current and voltage were under independent and accurate control, and the focal spot was of known and unvarying size and fixed location, we were in a position to attempt the solution of the mystery concerning that occasional outstanding roentgenogram that could not be duplicated. As a subject was needed, I called on one of my medical friends for assistance. (I had temporarily and unintentionally sacrificed my own back hair to previous experiments and did not like to practice on other living subjects.) My friend provided me with material which was very useful over a period of months. I wish that I might make fitting acknowledgment at this time to the willing and complacent subject of those experiments. (I can't think of it even today without smelling formalin.)

Later experiments with the detached leg of another passive subject led to a serious misunderstanding. For, upon the completion of these experiments, we wrapped the member in question in a fabric which was easily available to us, varnished cambric, and took it to the works' incinerator. The operator in charge removed the cover and we inserted the package, making no attempt at explanation, as the attendant did not understand much English. It seems that after we left, he raised the cover of the incinerator, and, looking into the fiery furnace, saw our varnished cambric unwrap itself, revealing the seeming evidence of a ghastly crime. We later received a visit from our works' detective, who was in a very serious mood. We explained and explained, but have never been sure that he has ceased to regard us with suspicion.

The conclusion drawn from these experiments was that there was no mystery—that, other things being equal, contrast was determined solely by the voltage used and that definition was a function of the size and fixity of position of the focal spot. We concluded that if one had his choice he would not use the mixture of rays which the tube gives, but would take monochromatic radiation of a wavelength dependent on the thickness of the part to be roentgenographed; but that, not having this choice, he must be content with that mixture of rays coming from the tube when operated with the voltage which gives the desired contrast. Increasing the breadth of the spectrum used, by making a part of the exposure with low voltage and the rest with high, did not help.

Field Currents

It appeared early in the course of our work that if cathode and target were brought very close together, or if there were a sharp point on the cathode, a high voltage discharge could take place even from a cold cathode and in the highest attainable vacuum.

In poorer vacua a similar effect had been observed and described by H. A. Rowland, N. R. Carmichael and L. J. Briggs and by R. W. Wood.

Upon learning that electrons could be pulled out of a cold cathode even in the highest vacuum by means of a high potential gradient, the question arose as to whether a tube based upon this principle might not, because of the greater simplicity involved in the control equipment, be more attractive than a hot cathode tube.

Extensive efforts which we made at the time, however, as well as all subsequent experience, have borne out the conclusion then reached that such a discharge is not

sufficiently stable. Nor does it offer the great flexibility of the hot cathode tube permitting independent control of milliamperage and kilovoltage.

Multisection Tubes

Not only did we decide not to make use of field currents but it soon developed that we must take steps to avoid them, as they otherwise set a limit to the voltage which a tube could support. For operation at high voltage we found it helpful to avoid sharp edges and corners on the electrodes and to space them well apart. Even with these and other precautions, however, it proved difficult to get above a few hundred thousand volts until we hit upon the expedient of grading the potential by means of auxiliary electrodes. The resulting cascade tube made it possible to avoid field current limitations, and so to build tubes for any desired voltage.

Radiator Tube Developed for World War I

World War I brought interesting experiences in connection with the development of roentgen-ray equipment. For use near the front it was clearly desirable to have a simple self-contained and dependable generating outfit of adequate power and maximum portability. It was obviously desirable to eliminate if possible the mechanical high voltage rectifying switch which was in general use at the time. This was before the days of the kenotron but was still possible if we could develop a hot cathode roentgen tube which could be depended upon to rectify its own current. To meet this requirement it was imperative that no part of the focal spot should ever reach the temperature at which appreciable thermionic emission would take place, as this would lead to electron bombardment of the cathode filament raising its temperature and causing run-away with consequent destruction of the tube. One factor was very favorable—the amount of available energy was going to be definitely limited by the capacity of the gasoline-electric generator. The "Universal" tube with its solid tungsten target would have been safe for occasional use, starting with a cold target, but not for the very frequent use which the war service required. These considerations led to the development of the "Radiator" tube with its composite target, heavy copper stem and external radiator for rapid heat removal. The target itself was that which had been developed earlier for the gas tube, but much experimentation was required before we were able to free the large mass of copper sufficiently from gas. For roentgen-ray protection, a heavy two-piece lead-glass shield was developed to completely surround the tube. This tube and shield served for both the United States Army Portable and Bedside outfits.

Power Plant for United States Army Portable Outfit

I knew of no light weight gasoline-electric set suitable for the power supply of the Portable outfit. It seemed possible that a motorcycle could to advantage be used as a highly portable power supply and belted to an electric generator at the point where roentgen rays were required. Through the courtesy of the Indian Motorcycle Company, I was provided with a motorcycle and on it I took my first motorcycle ride. One experience was enough to satisfy me that this was not the way to treat the roentgenologist.

Through the application of tungsten contacts in the automobile ignition system, I had become acquainted with Charles F. Kettering, then of the Delco Company, and this connection suggested the one-kilowatt house lighting set of that company. This was a light weight, 32 volt, gas engine driven, direct current generator. We needed an alternating current generator and, for ready adaptation to a high voltage transformer which we had found already in production by the Victor X-Ray Company, we required 115 volts. The Delco Company obligingly made changes required in the generator, but the engine did not respond well to having the full

roentgen load thrown suddenly upon it. So I asked for Dr. Kettering's personal assistance. He generously came to Schenectady and spent a whole week with us in so modifying that engine that it would promptly accept the suddenly applied load.

Adapting the Roentgen-Ray Generating Equipment to the Table

Dr. John S. Shearer, then professor of physics at Cornell University, had assumed the responsibility for the design of the "Portable" table and he cooperated closely with us in harmonizing table and roentgen-ray source.

Packaging for Shipment of Tube to the War Zone

Shipment of the tube caused us much worry at first. Our experience was all in favor of a light weight, open-work crate permitting the handler to see the glass, and so making him constantly aware of its fragility. But Army shipping instructions called for a solid crate suspended from the corners of another solid crate and we were told that the tube so packed must stand dropping from a dray onto a stone pavement. We found that our tubes would stand this treatment, but, in the first lot shipped abroad in this way, 40 per cent were broken. We were then permitted to use our fragile open-work crates and, when shipped in this way to the war zone, only 1 per cent were broken.

Development of Oil Immersed Equipment

The fact that the hot cathode tube could be made very small, especially for oil immersion, and could rectify its own current and had a long life and did not need to be seen during operation, made it seem very attractive for installation in the same metal container with the transformer serving as the source of high voltage. In this way it was easy to secure excellent roentgen-ray protection, as well as protection from electric shock. Many small outfits of this type have been used for dental work and other purposes, while larger ones have been used for therapy.

Induction Coil Development

In connection with our work on what might be called a glorified Lenard tube, we had tried to develop the induction coil for very high voltage. Using a mercury turbine interrupter for the primary current, we had succeeded in getting up to 900,000 volts. The difficulties, however, increased rapidly with voltage and it looked very difficult to go much higher by this method.

Break in My Active Experimental Work

In 1932, when I became director of the Laboratory, Dr. E. E. Charlton was made head of our roentgen-ray section and, ably assisted by W. F. Westendorp and others, still holds that position. Since then I have been able to devote much less time to this field, but have had the privilege of being a very interested observer.

The Resonance Transformer and the 1 and 2 Million Volt Outfits

My earlier experience with the induction coil and other high voltage sources has made me very appreciative of the low frequency resonance transformer developed by Mr. Westendorp. This required no iron in the center, thus permitting the roentgen tube to be placed there where it would be electrostatically shielded by the transformer and where the connections between tube and transformer would be very short and also completely shielded.

It has been very interesting to watch the development in Dr. Charlton's section of the 1 and 2 million volt roentgen outfits employing the resonance transformer and compressed gas insulation. By this method it looks practicable to go still higher to perhaps 4 or 5 million volts and with several milliamperes of current.

The Betatron

It has also been a pleasure and a privilege to watch the development of the betatron. After Dr. D. W. Kerst, working at the University of Illinois, had built a successful small machine, giving 2.3 million volt roentgen rays, he procured a leave of

absence from the University and joined our research staff for over a year. While he was here, with the help of Dr. Charlton's group, a larger machine embodying the same principles was designed and built. This operated satisfactorily at 20 million volts. We have since then built a still larger machine of the same type which gives roentgen rays of any voltage from 2 million up to 100 million. The fact that it has been possible to go so directly from Dr. Kerst's first machine to one giving over forty times the voltage would augur well for future further advances in this direction.

Significance of Röntgen's Discovery

During the past fifty years the roentgen rays have indirectly greatly extended our vision. Our eyes respond directly to a region of the spectrum which is only one octave in length. The rays were first produced by Röntgen at perhaps 25,000 volts. Through the years we have gradually worked up to a few million volts and now, with the betatron, to 100 million volts. In the other direction we have gone down to as low as 1,000 volts. The roentgen spectrum available today then covers a range of more than sixteen octaves and indirectly extends our vision to this extent.

The roentgen rays have shown us the relation between the various chemical elements. They serve as a means of chemical analysis. They enable us to measure the distance between the atoms in a crystal and so to determine crystalline structure.

They perform an invaluable service in medical diagnosis and are a powerful therapeutic agent in the treatment of human ills.

They occupy a rapidly expanding place in industry, where they are used to show cavities and foreign inclusions in structural and other materials, to indicate whether vital internal parts of a structure are present and in proper position, and recently as a thickness gauge which does not require contact with the part to be measured.

The very low voltage roentgen rays are used in microroentgenography as a means of studying the composition of very thin metallic specimens and to reveal structure in delicate botanical and zoological tissues. They may be used to produce genetic changes in plants and animals.

Lastly, and to the physicist most important, the roentgen rays have perhaps more than any other single agency advanced our knowledge of the structure of matter.

At the close of these rambling reminiscences I take the opportunity to acknowledge the help and the pleasure which I have derived from the close association which I have had through the years with the many doctors, dentists, physicists, industrialists and others interested in the various uses of roentgen rays.

EARLY AMERICAN ROENTGENOGRAMS

By OTTO GLASSER, Ph.D.
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THE question, "Who made the first x-ray picture in the United States after Röntgen's announcement of the discovery?" has frequently been raised but never conclusively answered. Intimately related to this question is another: "When did news of the x-rays reach the United States?"

Although Röntgen made his first observations on the effects of a new kind of rays as early as November 8, 1895, he talked with no one about the discovery until he handed his first "preliminary communication" to the secretary of the Würzburg Physical Medical Society, December 28, 1895. New Year's Day, 1896, he mailed to certain colleagues reprints of this paper together with copies of his first x-ray pictures. Because of the enthusiasm of some of these colleagues, word of the sensational discovery quickly reached the newspapers, the first report appearing in the Sunday edition of the Vienna *Presse*, January 5, 1896. The next day the news spread to all Continental papers and was cabled throughout the world:

> The noise of war's alarm should not distract attention from the marvelous triumph of science which is reported from Vienna. It is announced that Prof. Röntgen of the Würzburg University has discovered a light which for the purpose of photography will penetrate wood, cloth, and most other organic substances.

Thus, American papers printed news of the discovery at the same time, or even before, it appeared in Röntgen's hometown newspaper, the *Würzburger General Anzeiger*, January 9, 1896. The *Cleveland Plain Dealer*, for example, printed an editorial on the new rays January 9, 1896:

> An Austrian professor has discovered a light, which "makes light" of the most opaque obstruction to the photographic lens, and enables him to photograph boxed metal objects with a draped camera without a trace of the intervening wood and cloth, and broken arms, and bullets in the human body without evidence of the concealing flesh or skin. . . . It is a singular story, but vouched for and explained by the use of certain rays which penetrate organic matter and other opaque substance just as ordinary rays penetrate glass.

Within the next few weeks numerous papers, journals, and magazines published more detailed descriptions. Workers in many laboratories equipped with induction coils and evacuated glass tubes of the Hittorf-Crookes type reproduced Röntgen's results. Just which one was the first to do so is uncertain.

Richtmyer in a report to *Science*, 1932, made the following statement: "It is said that within forty-eight hours after American newspapers had printed the cable dispatch reporting the discovery of x-rays, at least six x-ray photographs had been made in laboratories on this side of the water." A thirteen year study of available information has failed to reveal American roentgenograms definitely dated early January, 1896, or otherwise incontestably identified.

Statements to the contrary must be considered doubtful. One of the best known was made by M. I. Pupin in "From Immigrant to Inventor:" "I obtained the first x-ray photograph in America on January 2, 1896, two weeks after the discovery was announced in Germany." Since the discovery was not announced until early January in Germany and was not cabled to America until January 6, and since cable messages received in the United States before these dates revealed no advance information, I asked Pupin, December 18, 1929, for further information on his early roentgen-ray work. He answered:

The first news of the discovery of x-rays was sent to me by a friend, a physicist in Germany. I also saw an announcement of the discovery in one of the New York papers. All this happened several days prior to January 1, 1896. I have no records to prove this; nothing but memory. I have no copy of my first x-ray picture, and I do not believe that it is possible to obtain one. . . . I am sorry that I cannot help you out with more definite information. But experimental data obtained in my laboratory so long ago are not likely to be recorded anywhere. I never had the habit of keeping data of a certain piece of experimental work after the work was finished and published.

"Roentgen Rays," Pupin's first report on his experiments, was written February 8 and published in *Science* (Vol. 3, p. 231) for February 14, 1896. It seems very likely that Pupin made his first x-ray picture February 2 instead of January 2 which was approximately "two weeks after the discovery was announced in Germany." It is entirely possible, however, that Pupin's roentgenogram was one of the first made in the United States.

Similar uncertainties cloud other reports of early roentgenograms in this country. This situation is complicated by the fact that the first x-ray photographs were made by physicists and photographers. Some weeks passed before physicians availed themselves of this new diagnostic method. Yet naturally, from their point of view, they considered their efforts with the newly discovered rays the earliest ones.

Historical study indicates that the earliest roentgenograms in the United States and Canada were made by the following scientists: F. Cajori of Colorado College, Cox of McGill University in Montreal, T. A. Edison and his assistants, E. B. Frost of Dartmouth College, D. W. Hering of New York University, A. W. Goodspeed of the University of Pennsylvania, T. J. Houston, E. C. Jerman of Chicago, A. E. Kennelly, E. Merritt and G. S. Moler of Cornell University, D. C. Miller of Case School in Cleveland, C. L. Norton of Boston, M. I. Pupin of Columbia University in New York, Dr. Henry Louis Smith of Davidson College, J. P. C. Southall of Miller Training School of Albemarle in Piedmont, W. M. Stine of the Armour Institute of Technology, J. Trowbridge of Harvard, and A. W. Wright of Yale University.

While collecting material for my Röntgen biography, I had the good fortune to have advice and information from many of these early American roentgen-ray pioneers. Nothing illustrates better their interest in the new discovery and their diligence in working it out than quotations from their original letters. These statements also throw light on the difficulty of determining who took the first roentgenogram in the United States.

F. Cajori of the University of California claimed that he and a colleague were the first in Colorado to show roentgen-ray effects. On January 12, 1930, he wrote:

As I remember, the news of the discovery of x-rays reached me in Colorado College, just as I was completing the MS to my "History of Elementary Mathematics," December, 1895. I remember taking the MS on my bicycle down to the express office, and, the same evening starting in with my good friend, Professor William Strieby, to try for x-rays. I had at Colorado College a fairly good Ruhmkorff coil and a few Crookes tubes. We got some shadows of vegetable substances that evening, which we were inclined to consider due to other than x-ray effects. The next day we got the first shadows from metallic plates. . . . We were the earliest in the State of Colorado to show the x-ray effects.

Records and publications proved that Henry W. Cattell of Philadelphia worked with roentgen rays as early as February 1896. On December 21, 1929, he wrote:

My work was sent out first by associated press dispatches, before being published in February, 1896, in the *Medical News* and in the *International Medical Magazine*. I have my first records.

In a second letter, February 5, 1930:

I coined the words skiagraph and skotograph. . . . I had, as far as I know, the first portable x-ray outfit in America; I went to Queen's and

bought up all the Geissler and Crookes tubes they had, and my first exposures seen in the *Medical News* of February 15, 1896, took twenty minutes to half an hour.

In a third letter, April 1, 1933:

I still have the things that I had in my portable x-ray apparatus in January, 1896. . . . When I made the skiagraphs in January, 1896, I had never seen a Roentgenogram, and naturally they are very crude.

William H. Dieffenbach of New York wrote on January 8, 1935, that a roentgenogram of his hands was the first taken in the United States:

In January, 1896, I was a student with Dr. William Hardey King who had a large static machine in his office. When I called his attention to an article in the *Literary Digest* of January, 1896, telling of Röntgen's new discovery, Dr. King secured a Crookes tube and hitched it to the static machine and tested out the radiation on my hands—exposing same for several minutes. I had the plate developed at a nearby photographer's, and this was, I believe, the first plate taken in the U.S.A. The date is fixed in my mind as the middle of January, 1896.

Edwin B. Frost of Dartmouth College began his experiments with roentgen rays the last of January, 1896. On January 24, 1930, he wrote:

On the basis of fragmentary news that was published in American newspapers by cable from Germany, I began experimenting in the Physical Laboratory of Dartmouth College in the last days of January, 1896; but I cannot now state positively whether my first picture was obtained on Saturday, January 24, or February 1. I had my article for *Science* finished on February 4, and it was published ten days later, along with articles by M. I. Pupin, and A. W. Goodspeed, whose papers are dated four days later than mine.

In a Cornell University museum, E. Merritt discovered evidence of his early work in roentgen rays. A letter from him on September 26, 1929, states:

I find in our department museum three early x-ray pictures, two made by Professor Moler and one by myself. Those made by Professor Moler are shadow pictures of various metal objects like keys and chains which had been placed inside of a pasteboard box and then photographed. Our records do not show the exact date, but Professor Moler had written on the back of them that they were taken after the news was received of Röntgen's discovery, but before Röntgen's first pictures had arrived.

Dayton C. Miller of Case School of Applied Science realized that his early roentgenograms were not dated and cannot be claimed as the earliest ones. He said on February 20, 1933:

In January, 1896, cabled news appeared announcing Röntgen's discovery of the x-rays. The Physical Laboratory of Case School had purchased the complete set of Crookes tubes which had been exhibited by the firm of Geissler of Bonn, Germany, at the World's Columbian Exposition, Chicago, 1893. Experiments were begun immediately, and several tubes were found which produced x-rays. . . . We first succeeded in photographing some inanimate objects. Then we photographed the hands of Mrs. Miller, and this was published in the newspapers. We think that this picture was the first one in this part of the country, but let me say that it was perhaps taken in the same week as pictures taken at Columbia University, University of Pennsylvania, Bowdoin College, Amherst, Harvard, and many other places. Many of these early pictures were not dated so that they cannot claim to be the earliest one.

Yet P. C. Southall of Columbia University claimed that his were the first roentgenograms made in this country. On December 20, 1929, he wrote:

In the year 1895 I was the head of the Department of Physics and Mathematics at the Miller Manual Training School of Albemarle in Piedmont, Virginia. I had a beautiful collection of Crookes tubes and every facility for doing this kind of work, when a meager report of Professor Röntgen's discovery was cabled to this country. I read an account of it in the newspapers, and a day or two later I had succeeded in obtaining x-ray radiographs of coins and a bunch of keys. As far as I know, these were the first x-ray photographs that were ever made in this country.

W. M. Stine of Pennfield, Pa., in a letter of July 10, 1930, told of the success of his colleague, A. A. A. Atkinson:

As I was resuming my experiments for the third time, there came the news of Röntgen's discovery. . . . I lost no time in sending to my successor at the Ohio University at Athens, Professor A. A. A. Atkinson, precise directions for setting up the apparatus exactly as I had had it for my first experiments. He explicitly followed my directions and was immediately successful.

Experiments were begun by D. W. Hering of New York University the first of February, 1896. He wrote on December 24, 1929:

New York University was fortunate in possessing a fine set of Crookes tubes, such as were then supplied from London for the repetition of Professor Crookes' remarkable experiments with cathode discharges in high vacua, but our only means of exciting them were an induction coil producing a spark of scarcely three inches in air and a good Toepler-Holtz plate machine giving a spark of six to eight inches. . . . I began experimenting about the end of January or the beginning of February, 1896, and began to get pictures in the first week of February.

C. C. Hutchins of Brunswick, Maine, made and used roentgen-ray tubes of his own soon after news of the discovery. This he reported in a letter of December 20, 1929:

As soon as the news of the discovery reached America I overhauled my collection of Crookes tubes, selected the most suitable one and therewith made a photograph of a single finger of Dr. G. M. Eliot, a local physician. There happened to be in my laboratory a very good mercury pump, and I happened to be a pretty good glassblower, so I set to work on x-ray tubes of my own, with success from the first. . . . As I now remember I had these tubes in use inside of two weeks of the arrival of the news of the discovery.

The shipment of a Crookes tube held up Ed C. Jerman's experiments. As he said on August 29, 1930:

When Röntgen's paper was broadcast to the world the latter part of December, 1895, and during January of 1896, first through the lay press and quickly followed by the scientific press, I quickly found that I had all the equipment necessary for producing the x-rays except a Crookes tube. I finally succeeded in getting a Crookes tube, imported through Oelschlaeger of New York. I received this tube in March, 1896, and my first successful exposure was made with a small Pattee two plate static machine.

A. E. Kennelly of Harvard University studied the new rays with Edison in January, 1896. On December 26, 1929, he wrote:

When the news of the new roentgen rays reached America by cable early in January, 1896 Mr. Edison took up their study, and invited me to see some of his experiments at his Orange laboratory. I spent from January 27 to February 2, 1896, with him. . . . Professor Houston and I had already repeated in a crude fashion a few of the Röntgen experiments, as announced by cable, in our laboratory at Philadelphia, using an induction coil and a few Crookes tubes that were purchasable in Philadelphia. We had obtained x-ray pictures on ordinary photographic plates of coins, keys and similar objects.

R. H. Lafferty of Charlotte, N. C. verified his early experimentation with roentgen rays by a print from his first plate. In a letter of June 18, 1931, he said:

Osmond Barringer, Eben Hardie and Pender Porter of Davidson College, on Sunday night, January 12, 1896, slipped into the laboratory and made a picture on a kodak plate. It required about three hours' exposure. . . . The only corroboration that I have of the date, January 12, 1896, is: first, that I recall the event as coming quite soon after our return from our Xmas holidays; second, I do not have the plate that was made but did have the print from which a cut was made; on the back of this was the date, January 12, 1896. This plate is now in the Archives of Davidson College.

W. H. Meadowcroft of Orange, N. J. reported that Edison began experiments immediately. On January 25, 1930, he wrote:

Mr. Edison opened your letter and asked me

to say to you that within two days after the original announcement of Dr. Röntgen was cabled over from abroad, he, Mr. Edison and his assistants commenced experimenting along the lines indicated in the cable from abroad. In four days Mr. Edison had achieved the same results.

A. W. Goodspeed of Philadelphia claimed accidental discovery as early as 1890. In his letter of February 15, 1929, he wrote:

My early articles on "Roentgen Rays and their Applications" were published in the *Proceedings of the American Philosophical Society* in January, 1896, and in *Science*, February 14 and March, 1896.

The accidental roentgen rays' effect which W. N. Jennings of Philadelphia and I produced in 1890 was real and authentic. Because of our laxity in not following the matter up we do not claim any credit whatever but the facts are as stated in such articles as you may have read.

It seems to be impossible to state with certainty who took the first roentgenogram in the United States. However, this question becomes somewhat academic in view of the tremendous interest with which Röntgen's discovery was received and quickly repeated in many laboratories in this country.

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THE ROENTGEN EXAMINATION IN OCCUPATIONAL DISEASES OF THE LUNGS

A HISTORICAL DISCUSSION OF ITS USE*

By EUGENE P. PENDERGRASS, M.D.
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PNEUMOCONIOSIS is a generic term used to describe all forms of pulmonary reactions to dust lodging in the lungs. These changes may or may not be demonstrable by the roentgen examination. Other terms such as siderosis and anthracosis are special names which serve to indicate the lung condition occurring in certain industries (iron and coal mining).

It is generally conceded that the roentgen examination of the chest, carefully done, is the most precise method at our command for demonstrating physical shadows of pathological changes in the lungs produced by some dusts. Unfortunately, there are many other conditions that produce shadows in the roentgenogram which may simulate some of the various shadows found in pneumoconiosis. I always have regarded the roentgen examination as a consultation, and used as such it is likely to be more valuable. It, therefore, behooves those of us who utilize chest roentgenography to consider all of the various lesions that may produce lesions simulating pneumoconiosis before arriving at a diagnosis; otherwise mistakes will be made.

In a review of the literature on pneumoconiosis from 1895 to 1899 I found only one article in which roentgenography was employed. A French physician, Oddo,[34] reported a case of anthracosis in a male, aged fifty-eight, in whom a roentgen examination of the chest showed multiple shadows in both lungs (sclerose pulmonaire) which were interpreted as anthracosis. An autopsy substantiated the diagnosis of anthracosis (Fig. 1).

In preparing this historical review, I have had occasion to peruse essentially all of the early English, German, and French radiological periodicals. Many of these were on general subjects but I was impressed with the comparatively few publications on the roentgen diagnosis of conditions involving structures within the thoracic cavity. This was not true of the American literature, however. The early publications of Williams, Caldwell, Newcomet, Crane, Kassabian, Hulst, and many others, were most noteworthy. The most comprehensive treatises on the chest were probably those of Crane and Williams, and it would be most stimulating and enlightening for all radiologists to search out the publications of these and other authors in order to learn how careful were the observations in those early days of our specialty.

In Williams' book, "The Roentgen Rays in Medicine and Surgery," he devotes eleven chapters to the chest, excluding the esophagus. There are 757 pages in his book, and 297 pages are allotted to chest diagnosis. When one looks at more recent publications, one cannot but admire the foresight of Dr. Williams. The chapters devoted to chest diagnosis are as follows:

Chapter III. *Methods of Diagnosis.* Williams discusses the use of the fluorescent screen and the roentgenogram.

Chapter IV. *Introduction to the Thorax.* In this chapter he discusses the appearance of the heart, the lungs, and the diaphragm in the healthy chest.

Chapter V. *Pulmonary Tuberculosis.* This is a long chapter devoted to the diagnosis of early tuberculous lesions and the comparative value of the fluorescent screen and roentgenogram in diagnosis. He calls attention to the value of making roentgen examinations from time to time in persons from fifteen to thirty years of age if there is a family history of tuberculosis. Williams stated: "In this way, . . . early warning

* From the Department of Radiology, Hospital of the University of Pennsylvania.

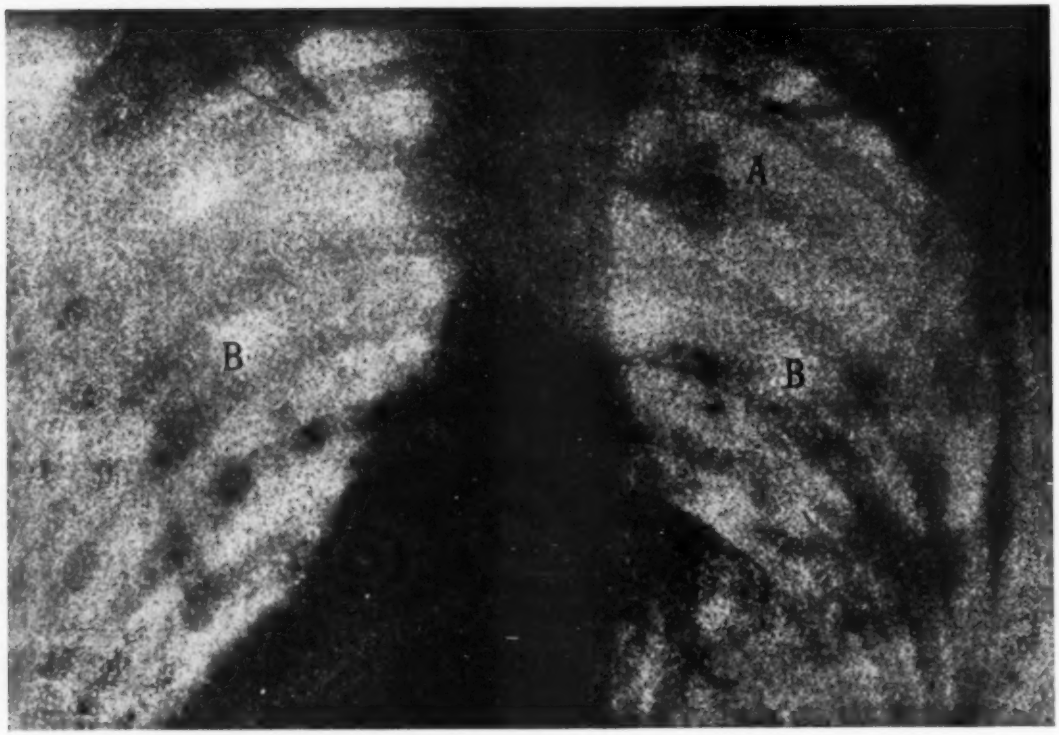

Fig. 1. Illustration taken from Oddo,[34] published in 1899, showing what he described as "sclerose pulmonaire" in a case of anthracosis.

would be given, and the best opportunity for its arrest obtained." He called attention to the greater accuracy of the roentgen examination over that of auscultation and percussion, and the frequency with which the roentgen diagnosis was confirmed by autopsy. He discussed acute and chronic tuberculosis, tuberculosis complicated with other diseases, tuberculosis with effusions and cavities.

In the concluding paragraph of this chapter Williams makes the following statement:

> All who are experienced in making physical examinations of the thorax recognize the necessity of controlling one method of examination with another. Not infrequently we understand best the conditions present, as just suggested, by taking into consideration the information obtained from inspection, percussion, and auscultation together, and if we fail to do this we may err in our diagnosis. The x-rays give another and valuable method for controlling the results obtained in other ways, and also add to them. We may, by their use, not only control one method by another, but with the eye supporting the ear we also control one sense with another.

Chapter vi. *Pneumonia.* Williams, in pneumonia, as in tuberculosis, used the roentgen examination of excised lungs as a basis for developing his diagnostic criteria. Frequent examination with drawings of screen observations demonstrated the progression and regression of the lesions.

Chapter vii. *Emphysema of the Lungs. Bronchitis.*

Chapter viii. *Pleurisy with Effusion, Emphysema.*

Chapter ix. *Hydrothorax. Pneumothorax. Empyema with Permanent Opening. Pneumohydro- or Pneumopyothorax.*

Chapter x. *Normal and Abnormal Heart.* This is a magnificent discussion and the author emphasizes the value of following the results of treatment by roentgen examination.

Chapter xi. *Thoracic Aneurisms.*

Chapter XII. *New Growths. Enlarged Glands. Abscess and Gangrene of Lung.*

Chapter XIII. *Conclusion of Thorax.*

I feel quite sure that the relative rarity of the clinical suspicion of pneumoconiosis and other occupational hazards and the frequency of tuberculosis in Boston accounts for the lack of consideration given by Williams to the subject of pneumoconiosis.

Among the foreign authors in this period who had contributed to the advancement of chest diagnosis by roentgen methods, Bouchard, Béclère, Benedikt, Rieder and Rosenthal, Levy-Dorn, and Weinberger are especially noteworthy.

During the period of 1910–1920, the development of thoracic roentgenology was marked by increasing use of stereoroentgenography.[9] Concerted efforts were made to classify and standardize the shadow-complex of various lesions, especially tuberculosis. It was during this period that Rieder and Rosenthal, Entin, Boardman, Pancoast, Miller and Landis, and Lanza and Childs recorded the roentgen manifestations of pneumoconiosis.

Since 1920, many publications have appeared describing the roentgenopathologic manifestations of lesions in the lungs resulting from occupational hazards.

SOURCES OF DANGER

Gases.[59] In various industrial operations a number of gaseous products are used or liberated, which may have an injurious effect on the respiratory apparatus. Among others are the halogens (chlorine, bromine, iodine) and their combinations with hydrogen (hydrochloric and fluorhydric acids), sulfureted hydrogen, ammonia, chloride of ammonia, nitric acid and the so-called "nitrous" fumes, sulfur dioxide, phosgene, acetic acid, formaldehyde, acrolein, and fumes from smoke. These same gases, as well as such intermediary products as cyanide of phosgene, fluorine of dimethylarsine and of diphenylarsine, and sulfide of dichlorethyl, are chiefly met with in war gas factories.[59]

Dust. While the physical and chemical laws which control gases are accurately known, the physical properties of the various kinds of dust which constitute industrial dust are far from being defined. There are many classifications of dust recorded, but I shall include only two.

Thompson classified dusts as (*a*) *insoluble inorganic dusts* (irritating the respiratory passages), such as flint, silica, sand, carbon (coal, soot), brick dust, marble, granite, terra cotta, cement, asphalt, enamel, glass, quartz, lime (gypsum, plaster), meerschaum, phosphate (fertilizers), guano, emery, diamond dust, metal filings (lead, brass, iron, steel, etc.), pumice, and ashes; (*b*) *soluble inorganic dusts* (apt to be swallowed and absorbed), such as soluble arsenic, mercury, lead and silver compounds, metal filings of lead, brass, and zinc; (*c*) *organic dusts and fibers* arising from handling or manufacture of wood, bone, and shell, from fur, skins, hides and leather, feathers, brooms and straw, flour and grain, jute, flax (linen), hemp, cotton, wool (worsted, etc.), tobacco, felt, carpets, rags and paper, horsehair, and street sweepings.

Schürmann[54] differentiated dust, according to origin, into animal, plant, and mineral dust and dust from the artifacts. *Animal dust* is evolved with the working of ivory, horn, whalebone, bones, mother-of-pearl, hides, leather, bristles, sheep's wool, hair (horse, rabbit, and cow), and feathers; *plant dust* has its origin in industries working with grain, medical powders, spices, cotton, hemp, jute, flax, tobacco, wood, thick-shelled nuts, bark of plants (tanning industry), rags, shoddy, and paper; *mineral dust* is formed in the working of hard coal, marble, and other limestones and in connection with clay and porcelain industries, also pumice, sandstone, granite, and slates; *dust from artifacts* is found in the glass, glazing, enameling, tile, cement, Thomas slag, celluloid, iron, steel, bronze, galalith, and lead-alloy industries and in the chemical (especially dye) industry. He defined mixed dust as a mixture of polish-

ing materials and the fragments of the object being polished.

Drinker states that these classifications are without much practical importance, since in daily practice in industry the harmful effect is exercised more frequently by dusts mostly of mixed origin. Besides, what is most important is the physical and chemical constitution of the dusts and consequently their action on the system. An effort has been made to group under the heading "inert" a certain number of dusts; the number, however, is becoming more and more reduced since certain dusts, such as talc and asbestos, until recently considered as inert nevertheless have caused serious organic lesions among certain classes of workers. The majority of experts admit that the so-called "inert" dusts are not really inert when considered from the pathogenic point of view. Although at the outset they are not harmful and even when present in the workroom in large quantities some of them cause only transitory discomfort (sneezing, watering of the eyes, cough), it is certain that as the organic reactions diminish and the system seems to have recovered from the effects, they nevertheless finally attack it in a subtle manner, sometimes even seriously. The mucous membrane of the nose, the conjunctiva, and first the upper and subsequently the lower respiratory passages, the teeth, the skin, and often the digestive tract are subjected to the harmful action of these dusts.

With the development of new industrial processes new dust hazards present themselves; thus it behooves the industrial physician, the experimental physiologist, the chemist, the experimental pathologist, the pathologist, the clinician, and the roentgenologist to be constantly on the alert for changes which may be produced in the respiratory tract as a result of tissue reaction to inhaled dusts. Today, there are several lung conditions that are alleged to be due to occupational dusts in relatively new industries, which are not understood clearly, and about which no medical publications have appeared as yet.

A typical occupational disease is the pneumonia which attacks workers who handle basic slag as well as farm laborers who scatter it on the fields.[59]

Various writers have attributed primary tumors of the bronchi and of the lungs to the inhalation of dust. "Schneeberg disease"—pulmonary cancer from which the workers in the cobalt mines of Saxony suffer—is regarded as an occupational disease, although the etiology is not yet clearly established. In the United States it appears that cases of carcinoma of the lung have been observed among petrol refiners and that this resembles the cancer of the skin caused by paraffin.[59]

The problem of occupational asthma is reported to be the same as that of occupational anaphylaxis.[59] In many of the cases the occupational character of the disease is clearly defined. The anaphylaxis is caused by the pollen of gramineous plants, dust from threshing oats, from hackling hemp and flax, from jute or cotton when opening the bales, or from flour, causing millers' and bakers' asthma.

Cases of asthma of the same variety have been observed in chemists and upholsterers, caused by such chemical products as aspirin, arsenobenzoles, ipecacuanha or lead, as well as in persons who come in contact with dust of animal origin, such as feathers, down and animal scales and hairs. In the case of furriers who use "ursol," asthmatic attacks as a rule appear only in those who prepare or handle black furs, after several years of work, during which they may have experienced no ill effects. Simultaneously or independently of the asthma, cutaneous lesions may make their appearance—urticaria, acute and chronic eczema and erysipeloid forms, which have also been found in persons who wear furs dyed with "ursol."[59]

Cases of asthma have also been observed in florists, horticulturists and fruit pickers; they may also be accompanied by pruriginous dermatitis, and these cases are based on allergy acquired by the inhalation of vegetable dust, which often contains an *Acarus*,

Pediculoides ventricosus, its secretions and excretions.[59] Silk-spinners' asthma, caused by handling silkworms' cocoons (*Bombyx mori*) is accompanied by inflammation of the eyes and a pruriginous dermatitis (mal des bassines.)[59]

In the pneumoconiosis caused by soot, which is found among coal miners, chimneysweeps and stokers on trains, the lungs are very black, but are free from sclerosis. In the pneumoconiosis due to wood charcoal the lungs are not thickened, which is also the case with coal miners' lungs when the seams do not penetrate hard rock.[59]

Free silica and asbestos dusts are the most hazardous of all of the industrial dusts. The two clinically important forms of pneumoconiosis, silicosis and asbestosis, are due to these two dusts.

Experimental investigations have shown that most non-siliceous dusts exert no appreciable effects on connective tissues, the reaction is not progressive and does not terminate in a fibrosis appreciable on gross examination. It would seem, therefore, that if abnormal shadows are observed in roentgenograms of individuals exposed only to non-siliceous dusts some other condition is present.[48]

There are conditions known chiefly from the shadows they produce on the roentgenogram. These conditions such as baritosis, and the "false nodulation" of arc welders, are known as benign penumoconiosis.

The nonspecific pneumoconiosis due to reactions of the lung tissues to organic dusts are more important from the clinical than from the roentgenologic standpoint.[15] Oftentimes byssinosis (pneumoconiosis due to cotton fiber) may be present and not demonstrable by the roentgen examination. In general, it is assumed that most of the organic dusts may cause bronchitis with or without sensitization phenomena resulting in a variety of allergic symptoms.[15]

The diagnosis of silicosis and asbestosis is not easy. Even though the roentgen examination provides the best method of investigation, the diagnosis of pneumoconiosis should be made only by an experienced physician, exercising keen clinical judgment based upon a consideration of the present and past occupational history, past medical history, present complaints, and the clinical manifestations revealed by a thorough physical examination correlated with the laboratory reports and the roentgen examination of the chest.

There is so much on the subject of pneumoconiosis, it has seemed best to select for recording here a few of the investigations that have been carried on in the various countries to illustrate the extent of the hazard.

GREAT BRITAIN

England early recognized the importance of occupational diseases of the chest. In 1862, a commission was appointed to inquire into the health of men employed in metalliferous mines.[10] During the ensuing years, some of the most important experimental and pathological investigations were presented by English workers. However, there were very few clinical reports that emphasized the importance of the roentgen examination.

As late as 1934, Harper, a radiologist practicing in the South Wales coal fields, in a letter to the *British Medical Journal* said that more colliery men in South Wales had chest roentgenograms than in other places. This he thought was the reason for the high incidence of silicosis in his district. He felt that a similar experience would obtain elsewhere if more general use of the chest roentgenogram was employed.

In 1930 Merewether and Price and later Merewether reported on their studies in asbestos. These publications have greatly stimulated work in this recently discovered occupational disease. Later Sparks, and Wood and Gloyne made an effort to determine whether pulmonary asbestosis, like silicosis, paves the way for a tuberculous invasion.

AUSTRALIA

The rapid increase in Australia's population in the latter half of the last century was

due in large part to the discovery of rich alluvial gold fields in several parts of that continent. This stimulated prospecting and brought about the discovery of other metalliferous deposits. A large portion of the migrants came from mining districts in England and other countries.

Silicosis has been demonstrated in many of the mining fields and a high death rate from pulmonary diseases, including tuberculosis, has been evidenced in connection with the industry.

In 1919, in a study of the miners at Broken Hill the roentgen examination of the chest as a means of diagnosis of silicosis as an occupational disease was employed for the first time.[17] Again in 1922 the New South Wales Board of Trade utilized the roentgen examination in a study of the sandstone and siliceous rock workers of Sydney.

CANADA

Pneumoconiosis or silicosis or miner's phthisis has been scheduled as a compensable occupational disease in quarrying, stoneworking, metal grinding or polishing, and mining, for a number of years in Ontario, Alberta, and Saskatchewan.[53]

Silicosis has been studied from time to time in the gold fields of Ontario, at Porcupine, Kirkland Lake, Cobalt, and Sudbury. Granite cutters in Ontario were examined in 1928. Other examinations have been made among foundry workers and among sandblasters, as well as workers in marble talc, cement, brick, grain elevators, and artificial abrasives. These investigations were carried out by the Industrial Hygiene Division of the Ontario Health Department, where Cunningham, Riddell, and their associates, have done work on correlating clinical, roentgenological, and pathological findings in lungs of workers.

GERMANY

In Germany there has been considerable interest in the subject of pneumoconiosis.

Staub-Oetiker described the roentgen appearances of sclerobic lung as found in metal grinders and recorded, as have so many others, various stages of the disease. Ickert and many other German authors have discussed in detail the part that silica alone plays in the production of fibrosis and when complicated by tuberculosis. Many of these investigators emphasize that silica may produce considerable fibrosis without the agency of tuberculosis.

German authors more than others have contributed to the literature concerning the finding of cancer of the lung associated with pneumoconiosis. The Schneeberg miners were apparently the earliest workers in which cancer was recorded as a complication of pneumoconiosis. Davis *et al.* have included an excellent bibliography on this subject in their book.

ITALY

Italy has a rich heritage in pneumoconiosis which extends back to the clinical and anatomical observations of Ramazzini.

Bianchi has utilized the roentgen examination of the chest in his investigations of sculptors, hewers, modelers, and workers in grinding rooms.

It was in Italy that the interesting condition, baritosis, which is one of the benign pneumoconioses, was found among baryta ore workers and reported by Arrigoni.

NETHERLANDS

The roentgen examination of the chest was employed in 1923 in studying some of the stonemasons, and it was noted by Kranenburg that the roentgen examination was more accurate than any of the other methods employed.

SOUTH AFRICA

Great credit should be given to the South African investigators for their contributions to the subject of pulmonary dust diseases. Even though the roentgen ray was discovered in Germany and her pathologists had made notable contributions, it was in South Africa in 1911 that chest roentgenography was for the first time employed on an extensive scale.[45]

The reliance placed upon chest roentgen-

ography was well expressed by Watkins-Pitchford, chairman of the South African Miners' Phthisis Medical Bureau. He states that it is not safe to venture upon a positive diagnosis of silicosis without the assistance of "a technically satisfactory radiograph," which is so essential in all diagnostic roentgenograms of the lung. Steuart, roentgenographer for the South African Bureau at the time of his report, had 200,000 chest roentgenograms of 57,000 individuals in his files.

Very few reports of asbestosis have come from South Africa.

UNITED STATES

Although the United States was late in getting started in the field of investigation of occupational diseases of the chest, there are today more exhaustive studies being carried out in this country than any other place in the world. Particularly is this true in chest roentgenography. Lanza and Childs and my own former chief, Dr. Pancoast, are probably responsible, more than anyone else, for the early enthusiasm that was created for including roentgen studies of the chest as a part of any comprehensive investigation of occupational diseases of the chest.

The industrial processes in the United States are extremely varied. There are many dusts which modify the action of silica and silicates, so much so, that it is essential for one to be familiar with the industrial operations in order to interpret properly the pattern of the changes produced on the roentgenogram by the pathological process.

In this country, chest roentgenography has been included as a part of studies of the chest in workers in the following industries: abrasive, aluminum, asbestos, sand blasters, brick, cement, ceramics, clay, coal (hard and soft), copper mining, foundries, gold miners, granite, grinders, gypsum, iron, lead, marble, porcelain, pottery, quartz and sand, slate, spray painting, stone, tobacco, wood, and zinc industries.

There are many other workers such as arc welders, tin and beryllium workers in whom there are interesting roentgen findings.

At the present time, data are not available on the general incidences of occupational diseases of the chest in this country. Even with silicosis and asbestosis, the incidence would be difficult to obtain from our vital statistics. In most of the large and in a few of the small industries, however, the industrial physician is on the alert about occupational conditions in the chest. Likewise, Federal and State agencies are being requested with increasing frequency to make health surveys of workers in various industries. It is hoped, therefore, that in the not too distant future, reliable information concerning the incidence of occupational chest conditions will be forthcoming from our vital statistics.

In 1917, Lanza and Childs presented the first American classification of stages of the condition based upon roentgen findings. This has stood the test of time so far as appearances are concerned, although there have been some changes in opinion as to the pathological features. They divided the progress of the condition into three stages, which may be briefly described as follows: *First stage:* The root shadows are denser, and more extensive, and may show nodules; the trunk shadows are increased in density and breadth, with numerous punctate deposits of varying size along them; the appearance is symmetrical on both sides at first, but not so later; there is no difference in diaphragmatic excursion. *Second stage:* In addition to the foregoing, there are found fairly symmetrical, small, circumscribed, dense areas throughout both lungs, and later larger masses accumulate, usually at the lower part of the upper third, about the level of the root shadows; the domes of the diaphragms seem accentuated. *Third stage:* This differs from the second only in the extent of lung involvement, indicated by increased numbers of deposits and more massive grouping. Lanza and Childs then go on to describe more advanced fibrotic changes, with

heart, vessel and tracheal displacement and restricted diaphragmatic excursion which they were inclined to ascribe to a tuberculous complication which we now know may be due entirely to advanced silicosis, although tuberculosis may be a factor. This classification, with a few minor changes, answers the purpose admirably today.

During the same year, Pancoast, without any knowledge of the work of Lanza, developed a similar classification, differing only in minor details. However, since this classification was not in general use, Pancoast and Pendergrass suggested the following pathologic-roentgenological classification to overcome existing confusion:[40]

1. Peribronchial-perivascular-lymph node predominance { rapid / slow
2. Early interstitial predominance (Interferes with diaphragmatic movement) { with nodular appearance / without nodular appearance / rapid or slow
3. Late or advanced interstitial predominance
4. Nodular predominance { non-progressive / progressive
5. Advanced diffuse or terminal fibrosis { conglomerate nodular type / interstitial type / massive fibrosis type

This classification is most satisfactory from the standpoint of uncomplicated silicosis, but it has never become very popular among physicians interested in this subject.

A later classification suggested by an interested committee[44] is as follows:

It should be distinctly understood that the tabulation which follows applies only to *silicosis*, that form of pneumoconiosis resulting from the inhalation of dust with a high silica (SiO_2) content. Other forms, like asbestosis, are excluded from this consideration because their pathology is essentially different from that of silicosis.

The tabulation contains two columns: on the left are the roentgenological appearances and on the right are the corresponding pathological lesions. There is further subdivision to describe the appearances of (1) healthy lungs, (2) the uncomplicated silicotic lung, and (3) lung of silicosis with infection. The changes described under the first division are those compatible with a state of good health; and while they *may* be produced by the inhalation of relatively small amounts of silica dust, they are not sufficiently characteristic or advanced to substantiate a diagnosis of silicosis. Similar or identical appearances may also result from the inhalation of non-siliceous dusts, from certain infection, from cardiovascular disease, and from certain other rare conditions. The changes involved are for the most part confined to the lymphatics and perilymphatic connective tissues and do not affect the parenchyma of the lung. Since, by definition, silicosis is a disease characterized by nodular fibrosis in the parenchyma of the lung, these alterations, even when they may have been caused by inhaled silica, do not constitute a basis for a diagnosis of silicosis. The second group covers the discrete and conglomerate nodular fibrotic reactions of simple silicosis. The last group deals with silicosis complicated by infection. In the majority of instances the infecting organism is the tubercle bacillus, but the classification is sufficiently broad to include other types of infection. Certain criteria by which one attempts to differentiate various forms of infection will be discussed.

Roentgenological appearances	Histological appearances
SIMPLE SILICOSIS	
1. Nodulation.—Discrete shadows not exceeding 6 mm. in diameter, tending to uniformity in size,	1. Circumscribed nodules of hyaline fibrosis located in the parenchyma of the lung. Occasionally some

Roentgenological appearances	Histological appearances
density, and bilateral distribution, with well-defined borders surrounded by apparently normal lung shadow. The outer and lower lung fields characteristically show fewer nodules.	of these nodules may show microscopic foci of central necrosis.
2. Conglomerate shadows that appear to result from a combination or consolidation of nodulation usually with associated emphysema manifested by— a. Localized increased transparency of the lung with loss of fine detail. b. Intensification of the trunk shadows by contrast. c. Depression of the domes with possible tendency toward individualization of the costal components of the diaphragm. d. Lateral view: Increase in the preaortic and retrocardiac space with exaggerated backward bowing of the spine. Widening of the spaces between the ribs may or may not be present.	2. The result of coalescence of discrete nodules; an area in which the nodules are closely packed and most of the intervening lung is replaced by more or less hyaline fibrous tissue. The lung architecture is partially obscured. No demonstrable evidence of infection. Emphysema is a compensatory dilatation of the air spaces with or without thickening of the septa.

SILICOSIS WITH INFECTION

The characteristic appearances described under simple silicosis are modified by infection as follows:

3. Localized discrete densities and/or string-like shadows accompanying those of simple silicosis described above.	3. Strands of fibrous tissue, often along trunks and septa, with or without areas of calcification; indicative of "healed" infection.
4. Mottling.—Shadows varying in size with ill-defined borders and lacking uniformity in density and distribution, accompanying simple silicosis.	4. a. Areas of bronchopneumonia with or without caseation, i.e., acute infection. b. Lobular areas of proliferative reaction with or without caseation, i.e., chronic infection.
5. Soft nodulation.—The nodular shadows described under simple silicosis have now assumed fuzzy borders and/or irregularities in distribution. This change may or may not accompany simple mottling.	5. Perinodular cellular reaction either exudative or proliferative in character.
6. Massive shadows of homogeneous density not of pleural origin symmetrically or asymmetrically distributed.	6. Extensive areas of fibrosis probably due to organized pneumonia of tuberculous or nontuberculous origin superimposed upon a coexistent silicotic process. Outlines of normal structures may be partially destroyed.

COMMENT

For the first group of appearances we have adopted the nomenclature of the National Tuberculosis Association Committee and described the lungs as *healthy* rather than *normal*, as a perfectly normal adult human being is a great rarity. For a description of the roentgenological appearance of the healthy chest the reader should consult a paper by Pancoast, Baetjer, and Dunham in the American Review of Tuberculosis for 1927, vol. 15, pp. 429–471.

As already mentioned under 2, *Irregular exaggeration of the linear markings, with possibly some beading*, belongs in the healthy chest group even when found in persons with a history of considerable exposure to silica, for such changes are nonspecific in character and they do not involve the parenchyma of the lung. Silicosis as a clinical disease begins only when the lung proper is affected. Likewise, under 3, *Increased root shadow* may be of nonspecific origin and hence is not diagnostic. In the *early* stages of silicosis the mediastinal shadow may be widened, owing to the enlargement of the tracheobronchial lymph nodes from accumulated dust and cellular reaction to it; later, when specific fibrosis develops, the tissues generally contract and the nodes decrease in size. The changes described under 2 and 3 may be caused by many forms of irritation; if they are due to silica they are identifiable only by microscopic examination. They do not apparently interfere with respiratory function, and they are not of diagnostic significance.

The asbestos industry has grown extensively in the past quarter of a century. This has caused attention to be centered around it as a factor in industrial disease. In this country, the reports of Lynch and Smith, Lanza *et al.*, Shull, Pendergrass, and others, and the experimental work of Gardner have emphasized the importance of this condition.

The process is confined to the lungs and pleura and if the disease becomes sufficiently advanced it will produce definite increase in the markings of the lungs and thickening of the pleura.

One cannot conclude a discussion of this kind without pointing with pride to the early work of many of our colleagues not only in roentgenology, but electrical engineers and physicists and to the fundamental contributions in anatomy, physiology, and pathology; all of which have provided for the roentgenologists information from which it has been possible to develop criteria that have become so essential in rendering a diagnosis in occupational lesions of the chest.

Whereas, in the early days roentgenography of the chest was utilized only occasionally, today modern preventive medicine cannot be practiced intelligently unless a roentgen examination is a part of the program. Finally, the need for chest surveys has become so great, a new procedure, photofluorography, has been developed and the work of F. J. Hodges, Morgan, and Hilleboe has been outstanding in this country.

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FIFTY YEARS OF ROENTGEN RAYS IN GASTROENTEROLOGY

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A HALF century of medical progress, even in one branch of medicine, is a difficult subject for review in the brief space available in this special issue of our JOURNAL. In the field of gastroenterology the onward march has been paced by the evolution of roentgenological advance in instruments and technique. The advance of our knowledge of the motor and many other physiological processes in the alimentary and biliary tracts has depended to a considerable degree on the aid of the roentgen rays in the physiological laboratory and in the clinic. From the diagnostic standpoint no examination of the digestive organs is now considered complete without the information supplied by a roentgenologic study. Many of the medical and surgical therapeutic procedures utilized are conducted under roentgen-ray guidance.

Gastroptosis was described as far back as 1750 by van Swieten and in 1770 by Morgagni. Cruveilhier in 1849 gave further attention to ptosis of the stomach, speaking of it as "vertical dislocation of the stomach." Bouchard placed great emphasis on ptosis of the digestive organs. Glénard[101] began in 1885 a series of communications in which he attempted to explain dyspeptic troubles by gastric and intestinal ptosis. It was perhaps unfortunate that at the time of the discovery of the roentgen rays, Glénard's disease, as it came to be called, occupied such an important place in medical practice, especially of those physicians giving special attention to the digestive organs, for one of the first and what was then considered most important uses to which the new rays were put in relation to internal medicine concerned the position of the stomach and colon.

The first record of an investigation of the gastrointestinal tract with the help of the roentgen rays is found in an article by Strauss[212] (1896) who wrote of fluoroscopic observations on the stomach by using gelatin capsules, the kind used for the administration of castor oil, filled with reduced iron oxide and bismuth subnitrate. The shadows were only very indefinite and the investigations were discontinued. Hemmeter[117] (1896) suggested the use of a solution of plumbic acetate in a gutta percha bag which could be swallowed and later withdrawn.

In 1897 a number of investigators employed the roentgen rays for observing the digestive tube. Walsh[218] recorded observations on the upper contour of the liver in a case of hydatid disease, mentioned the possibility of seeing the lower border of the stomach faintly outlined with gas, and described his study of a patient with intestinal obstruction who for a fortnight before the observation had taken 15 grains of bismuth three times a day. Benedict[20] tells of using gelatin capsules containing reduced iron, in February, 1897, for the study of the alimentary tract but failed because of inefficient roentgen-ray apparatus. However, on July 13, 1897, this method was successful in 3 cases.

Walter B. Cannon,[28] while still a medical student, undertook some work at the suggestion of Professor H. P. Bowditch, of Harvard University, who in the autumn of 1896 expressed the belief that the roentgen rays would give assistance in observing gastric motor activity. Cannon's very first experiments related to the movement of food in the esophagus, for which purpose the goose was selected. The head and neck were surrounded by a tall pasteboard collar which allowed free movement of the head without constriction of the neck (Cannon and Moser[29]). His first account of roent-

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genologic observations of the stomach of the cat was given at the meeting of the American Physiological Society in May, 1897, and later results in December of that same year.

Roux and Balthazard[189] (1897) should be credited with experiments on the stomach of frogs, dogs, and men, utilizing bismuth-filled capsules covered with celluloid to keep them from dissolving in the digestive tract.

Williams[227] employed the introduction of gas or air into the hollow organs, especially the colon. For the esophagus he utilized a spiral wire, as suggested by Lindermann in 1897, or a metallic sound or a soft rubber tube closed at its inner end and passed into the esophagus, then filled more or less with mercury or lead shot. Williams made his first experiments with a suspension of bismuth subnitrate in 1897, and suggested that if the examiner did not wish the bismuth to pass into the intestine he might wash it out of the stomach with a lavage tube. He gave credit to Cannon, whose early work was done on animals, for assisting him in some studies on children in September, 1899. There is no doubt that the credit for the introduction of the use of bismuth subnitrate mixed with food belongs to Cannon and to Williams, though probably there were others who made use of small doses of bismuth for similar purpose, especially for the study of the esophagus. An early advocate of bismuth in suspension for studying the stomach was Metcalf,[156] of Chicago.

Holzknecht[124] studied the esophagus with reference to stenosis in 1900.

However, the credit for the employment of bismuth salts in large doses, after proving that the ingestion of large doses is harmless, belongs to H. Rieder[184] (1904) of Munich. The Rieder meal was a standard for roentgenologic study of the digestive tube for many years and still is. Other outstanding pioneers in establishing standards for the roentgenologic study of the digestive tube were Pfahler,[171] the first of whose numerous publications on the subject appeared in 1905, Hulst,[127] Skinner,[198] and Crane[77] in America, and Holland,[119] Barclay,[9] and Hertz*[129] in England.

Aside from the investigation of the esophagus, the chief attention of roentgenologists was given, as above mentioned, to the location of the position of the abdominal viscera. Glénard's work[101] was so fresh in the minds of the medical profession that the new method was regarded as a God-sent aid in locating the lower border of the stomach and the position of the colon. Such added emphasis was placed on Glénard's teachings that for two decades gastroenteroptosis continued to occupy an important place in the description of roentgen findings of the gastrointestinal tract. It remained for Moody[163] (1929) to record his studies on 1,000 healthy university students, conducted over a period of ten years at the rate of 100 a year, which led him to recommend the abandonment of the term "ptosis" as applied to the digestive organs, and today few physicians explain a patient's digestive symptoms on the basis of "ptosis." Certain important data relative to the topography of the digestive tube were provided by studies of Holzknecht[124] (1906), Jollasse[133] (1907), Hertz[131] (1909), and Mills[158] (1917), among others, especially concerning the relation of the position of the digestive organs to body habitus.

It is impossible in this brief space to attempt a complete listing of all the contributors to the application of the roentgen rays to the study of the digestive tube; only the high lights will be given. Holzknecht[123] (1906) reported on gastric peristalsis and described the roentgen findings in cancer of the stomach. Reiche,[183] in 1909, reported on gastric ulcer craters. Ashbury,[6] at the 1910 meeting of the American Roentgen Ray Society, presented a paper on the recognition of gastric and duodenal ulcer by the detection of barium retained in the ulcer crater. At that time his work received little attention; yet today this find-

* Hertz later changed his name to Hurst and his later writings are under this name.

ing constitutes the basic roentgen evidence of gastroduodenal ulcer. In 1909 Kästle, Rieder and Rosenthal[136] reported on a sort of moving picture method which they called bioroentgenography. Haudek,[115] in 1910, published his epochal work on the diagnosis of gastric ulcer, especially of the body of the stomach, describing the niche which ever since has continued to be known by his name.

About this time barium sulfate replaced bismuth preparations as the generally used opaque medium for gastrointestinal work. Carman[31] laid much stress on roentgenoscopy confirmed by roentgenograms. Cole[67,68] and George and Gerber[91,92] placed emphasis on obtaining the greatest possible roentgenographic detail in the gastroduodenal region, employing the screen chiefly as a finder to make sure of proper positioning of the patient. Together these pioneers laid the foundation for the elaborate detail of the technique employed at present in gastric roentgenology. Haudek's double meal, described by Holzknecht[125] in 1911, is still in use in many clinics.

Cole,[67] George and Gerber[91] and Carman[31] all laid stress on the direct evidence of ulcer and carcinoma, as did Haudek,[115] whereas previously Haudek's teacher, Holzknecht,[125] had elaborated a number of indirect roentgen-ray signs of gastric disease. For instance, Holzknecht's symptom-complex No. 1: "(1) Bismuth residue after six hours; (2) normal stomach shadow on the screen; (3) achylia. Diagnosis: Small carcinoma of the pylorus." Holzknecht felt that a residue after six hours (with the bismuth-bread mixture) indubitably pointed to an organic obstruction of the pylorus. He argued that the cause must be either stenosis or spasm of the pylorus, and since spasm never occurs with achylia but, on the contrary, with hyperacidity, the diagnosis under the above complex must be a small carcinoma; and it should be operable, otherwise there would be some defect in the shape or extent of the bismuth shadow in the stomach. Another example: symptom-complex No. 4: "(1) Small residue after six hours; (2) sensitive pressure-point over the stomach; (3) normal gastric shadow. Diagnosis: Simple gastric ulcer." It was requisite that the sensitive point should be demonstrated roentgenoscopically as coinciding with the lesser curvature of the stomach where ulcer was frequently situated. Other roentgen signs of ulcer consisted of gastric antiperistalsis, displacement of the pylorus upward and to the left making a snail form of lesser curvature, and a stable or spastic intermittent transverse contraction of the stomach causing an organic or spastic hourglass formation.

But Holzknecht also recognized the importance of bringing out the detail of the gastric lesion by compression with a "distinctor" or wooden spoon[44] and with manipulation of the stomach under the screen with the hand protected by a lead rubber glove, a technique later emphasized by Carman in developing the "pad sign" in gastric ulcer. The American school laid great stress on the direct signs of gastroduodenal disease, later extending the same principles to the study of the bowel.

Holzknecht in 1909 was already practicing the method of "aimed" roentgenograms which some of us in this country have continued to use for more than thirty years. He considered it of the greatest advantage in the course of roentgenoscopy to place a roentgen plate behind the screen without altering in the slightest the relative position of the tube and the patient, and to expose it, with only a momentary interruption of his roentgenoscopic study. He considered that under many circumstances the roentgenoscopic examination was a preliminary to the roentgenography and that the screen acted as a finder for the roentgen tube. This Viennese practice was the forerunner of the so-called "spot film" method now so popular in the United States. Any size of film exposed in this manner is really a spot film, but because of the small size to which the film must be reduced before in most minds it is entitled to the term "spot film," it seems that these tiny films might better be called "dot films." At any rate, the exclu-

tion of apparatus which permits instantaneous recording of interesting phases of roentgenoscopic observations constitutes an important phase of advance in the roentgenologic study of the digestive tract.

Another important development was the idea of Baastrup[8] in 1924, founded on the elaborate studies of Forssell,[84] who devised a method of coating the walls of the stomach with bismuth and distending it with air. Forssell,[87] Åkerlund,[4,5] and Berg,[21,22] as well as Schwarz,[197] Ledoux-Lebard,[146] Barclay,[10] Weber,[222,224] Templeton,[215] and many others, have elaborated on the method of visualization of the gastrointestinal mucosa. No longer is there an effort to fill the stomach or bowel with a large opaque meal; now one seeks rather to visualize the mucosal pattern and to complete the study with a minimum of contrast material. Nor is the main effort carried out fluoroscopically in preference to the roentgenograms. The screen studies serve for observation of peristaltic activities and for gross details, but for the fine details which are needed for sure diagnosis, one must have recourse to roentgenograms, including the "spot films" made with compression when needed, the preliminary fluoroscopy serving more as an aiming device and for observation of mobility and peristalsis than for recognition of fine detail. Let anyone with sublime faith in the fluoroscope prepare his eyes ever so well and then try to make his final diagnosis on a cholecystography or an intravenous urography with the fluoroscopic screen alone! The ideal examination of the digestive tube today includes appropriate use, as needed in the individual case, of all the fluoroscopic and roentgenographic devices which the past experiences have taught us.

To enumerate in this brief space the various steps in the progress of gastrointestinal diagnosis generally and of the colon in particular and to name the various responsible authors without serious omissions would be almost impossible. A great many of the advances in gastrointestinal roentgenology were begun independently and simultaneously by two or more roentgenologists, often continents apart.

The early examinations of the colon were carried out by the introduction of air or gas to outline the sigmoid flexure and descending colon, not only for the determination of the position of the large bowel but also for discovering and identifying enlargements of neighboring organs, such as the kidneys, spleen or pancreas (Williams). Williams[227] also suggested that the large bowel might be injected with a fluid containing subnitrate of bismuth and its outline and position studied. He added that "we should remember that any liquid which is opaque to the rays must be heavy and that the risk of putting into the large intestine such a weight as might be dangerous to its integrity should not be taken."

Groedel discussed at some length the study of the large bowel by following through the opaque meal, and in 1909[110] he recommended the bismuth clysma. At about this time Haenisch,[112,113] of Hamburg, had progressed so far in his use of the contrast enema that he had developed the trochoscope, especially designed for the study of the large bowel by the aid of the opaque enema. The Haenisch trochoscope was the forerunner of most of the horizontal fluoroscopic devices developed in the United States during the next decade.

For several years the practice became general in colon studies to use a large opaque enema, injecting until the colon was completely filled and some of the opaque material had found its way into the small bowel. But the growing appreciation of visualization of the mucosal pattern of various organs, stimulated by the work of Forssell,[87,88] and others, led to the development of combining the simple opaque enema with the injection of air or gas. The leaders in Europe were Fischer,[83] Berg,[22] Schwarz,[196,197] and in the United States, Cole,[73] Weber,[224] Gershon-Cohen,[97,98] and many others.

Among the first after Pfahler to carry out roentgen examinations of the colon by the opaque clysma on a large series of pa-

tients was Case[41,46] who had completed five hundred such examinations by the end of the year 1911. From the first he learned to stress the need of interrupting the fluoroscopic examination at appropriate intervals to place a film upon the patient underneath the fluoroscpic screen, exposing it with the same tube with which the fluoroscopy was conducted. He emphasized the value of turning the patient under screen guidance so that oblique and even lateral films of the sigmoid could be made in this manner. This fluorographic technique, which he learned from Holzknecht, of Vienna, was believed to be the earliest American application of the so-called "spot films" in mass studies of the colon. He also emphasized the value of localized compression with the Holzknecht wooden "distinctor" during the exposure of the films.[44]

From this, together with the double-contrast technique of Fischer,[83] Berg,[22] Weber[221] and others, has been evolved with minor modifications the present-day method of roentgen examination of the colon. The patient is first studied with the opaque enema, the injection of which is watched under the fluoroscopic screen for every inch of its extent. So-called spot films are made, especially of the sigmoid, of the flexures, and of the cecum, turning the patient under screen guidance as much as necessary to throw into prominence the coil in question. The entire colon is then recorded on a 14 by 17 inch film, after which the patient is allowed to evacuate the opaque enema. Another roentgenogram then records the degree of emptying and permits study of the more or less collapsed colon, the more complete the emptying the better. This is often the most valuable part of the study and frequently enables one to state with finality that there are no polypi or other tumors in the colon. Should question remain or there be other indications, air is then injected but this is not done in all cases by any means. After the air has filled the colon and localized studies with compression have been terminated, stereoscopic roentgenograms of the double-contrast-enema-filled colon are then made. The work of Weber and of Gershon-Cohen is particularly deserving of special mention in connection with the double-contrast colon studies.

Of course, during and prior to the time that the opaque enema was being developed, the colon had been extensively studied by observing the intestinal transit of the opaque meal. Holzknecht in 1909 described "rush peristalsis" or "mass movements" occurring in the colon, later further studied by Barclay, Case, Jordan, and many others.

In the colon the early work related to morphology, physiology and ptosis, with now and then papers on carcinoma, such as by Pfahler[176] (1911) and Case[45,65] (1913). Then came a period in which emphasis was laid upon intestinal adhesions, either of congenital origin or acquired, and we learned of Lane's kink and Jackson's membrane, the latter emphasized by Skinner[199] in 1914 and by Cole[72] in 1921.

Béclère[17] (1909), Liertz[148] (1910), Belot[19] and Desternes[82] (1911), Case[40] (1912), George and Gerber[90] (1912), were among the early contributors to roentgenology of the appendix. Since that time numerous publications on the appendix have appeared.

Although I have not attempted to include complete consideration of the work of European colleagues, review of the progress in roentgenology of the colon would be decidedly inadequate were we not to mention the work of Hertz (Hurst) of England. His contributions dealt mostly with the cause and treatment of constipation. The publications of Schwarz, then of Vienna, were scarcely less important.

Early contributions to the roentgen findings in ulcerative colitis were made by Stierlin[208,209] and Kienböck.[138] American contributors were particularly Carman and Moore,[38] Weber and Bargen,[225] and Kirklin, cooperating with Bargen. The relation of colitis to polyposis was discussed by Bargen,[12] and the diagnosis of polyposis by

Weber,[222] and others. Ileitis (Crohn *et al.*[80]) which was at first thought to affect only the terminal ileum has come to be recognized as an ulcerative disease which may attack any part of the intestinal tract.

The wave of deep roentgen therapy in the treatment of pelvic carcinoma has brought in its wake numerous instances of post-irradiation ulcers and other damage of the sigmoid. This was first published as far back as 1920 but recently the lesion has again found a place in the literature.

Colonic diverticula were first described roentgenologically by Goldmann[105] (Freiburg) in 1907, who described a case showing multiple sacculations; then by Abbé[1] and LeWald, Case,[47,48] Carman,[30] George and Leonard,[95] and Spriggs and Marxer,[202] until it has become generally recognized as one of the commoner and most important lesions of the large intestine.

Amebic, actinomycotic, blastomycotic coccidioidal and other fungus infections, endometrial manifestations in the colon (Jenkinson and Brown[132]), various types of fistula connecting the colon with abdominal and pelvic viscera and with the skin, Hirschsprung's disease, nonspecific granuloma, lymphopathia venerea, internal herniations and volvulus are among other important lesions of the colon which in later years have drawn the attention of radiologists. Many of these abnormalities and lesions are found also in other parts of the digestive tract.

Spontaneous pneumoperitoneum as a method of detecting internal perforations of hollow viscera was described by Lenk[147] (1916), Dandy[81] (1919), Copher[74] (1924), Vaughan and Brams[217] (1925), Pendergrass and Kirk[169] (1929), to mention only a few of the contributors.

Artificial pneumoperitoneum had its period of prominence with Stein and Stewart[203] (1919), Orndoff[167] (1919), Sante[190,191] (1921) and others, finally a collective review by Case[51] (1921) which showed that there was an inescapable element of risk, even of death, and considerably diminished the popularity of the method. Nevertheless, as with most methods overemphasized at first, there have persisted a few valuable uses for pneumoperitoneum. In South America the method was used very extensively for the diagnosis of abdominal hydatid disease, but a leading radiologist of the Argentine remarked that if it were not for the prevalence of hydatid disease in certain parts of the Southern Continent and in Australia, there would have been no such extensive use of pneumoperitoneum.

The realization that half of the malignant neoplasms of the large bowel occur in the rectum and rectosigmoid where they can be easily recognized by proctoscopic examination has impelled many writers to urge that every patient for whom a roentgen study of the colon is needed should have a preliminary examination of the rectum, at least digitally and preferably by proctoscope. Such preliminary examination will surely determine the presence of some early lesions which would otherwise escape even a most painstaking roentgen study. Small colonic lesions which are easily discoverable during the first moments of visualization of the rectum with the contrast enema can be completely lost when the rectum becomes distended.[63] To overcome the handicap of such a failure to diagnose, Oppenheimer[166] has recently described a special technique for the double-contrast visualization of the rectal and rectosigmoidal mucosa.

Up to this point, our review has concerned lesions of the esophagus, stomach, duodenum, and colon. In the field of the small intestine, which for a long time has remained a field only slightly known to roentgenology, great progress has been made within the last decade. In the earlier years of the roentgen era the motor physiology of the small bowel was an important part of the early studies, especially by Cannon, who described its motor behavior in great detail, including segmentation movements which occurred with such rapid alterna-

tions of segmental contraction and relaxation as to suggest the keys of a piano being played by unseen hands.

Various authors had written on acute and chronic obstruction, but it remained for Mills[159] in 1921 at a meeting of the American Roentgen Ray Society to relate his extensive statistical studies on the small intestine. He lamented the scant effort which had been directed to roentgen study of the jejuno-ileum, and made a valuable record covering observations on the digestive tract of 6,000 persons. Mills conceived that organic small intestinal lesions, involving the wall, either primarily or secondarily, will modify the roentgen shadow of the contents of the loops involved and thus render direct diagnostic evidence of their presence. This testimony might not be as striking as in the case of the stomach and colon, nor as suggestive of the nature of the lesion. He observed that when there is organic obstruction of the alimentary tract there will be dilatation and motor delay proximal to the lesion, depending upon the degree of obstruction.

In his series of nearly 6,000 subjects, atypical small intestinal patterns due to organic conditions primarily involving the small intestine were found in 70 cases, 18 of them being due to carcinoma and 44 to peritonitis and adhesions other than those due to appendical disease, and 310 were cases where the small intestinal atypical forms were a secondary result of organic disease, such as lesions of the cecum and appendix or complication of appendectomy, and lesions of the colon, such as carcinoma, diverticulitis, extra-alimentary tract tumor pressure, hernia, and a few other lesions. He included a group of 156 cases which he considered were due to functional pathological states. Many of these would no doubt now be placed under the head of insufficiency states, avitaminosis, as conceived today.

Cole[69] in 1914 had reported on the small intestine in relation to the stomach and cap as observed roentgenologically. In 1926, with Morse,[164] he made extensive studies regarding the normal anatomy and especially the morphology of the small intestine, showing that the position of the jejuno-ileum varied but little in the prone and erect posture; and that the loops of small intestine were shown with much better detail and with only slight distortion with the patient in the prone position. They felt that the roentgenographic outline of the inner wall of the intestine, as shown by the barium, was an expression not only of the surface of the mucosa but also of the muscular coats. They quoted Mall who taught that in the embryo there are six primary coils of small intestine. These can usually be identified in the adult. Loop one forms the duodenum; the second, third, fourth, fifth, and sixth loops or coils constitute the jejunum and ileum, otherwise referred to as the mesenteric small intestine. Other valuable contributors to the basic understanding of roentgenology of the normal and pathological small bowel were Soper,[200] Ritvo,[187] Menville and Ané,[155] and Bouslog,[25,26] to mention only a few of the many authors.

Schwarz[194] (1911) was one of the earliest to describe chronic obstruction of the small bowel, demonstrating dilatation of the small intestinal loops approaching the colon in size, exaggerated visibility of the circular folds of the intestine, fluid levels surmounted by gas in the dilated small intestine when the patient was examined in the erect position, and slowing of the intestinal transit.

These findings were corroborated in 1913 by Stierlin.[211] In 1914 Case[50,56,59,64] emphasized that it was possible to detect the presence of acute obstruction of the small bowel roentgenologically without the administration of an opaque medium given by mouth. This author repeatedly urged the feasibility of taking the roentgen examination to the patient with bedside roentgen-ray equipment, emphasizing that it caused the patient no more disturbance to slip a film under him than to place him on a bedpan. Many others have written on

the subject of acute small intestinal obstruction, including Sante[192] (1935). Wangensteen[220,221] in 1937 discussed at great length the value of the roentgen method in collaboration with other methods, particularly emphasizing that the roentgen ray furnishes reliable information, which can be learned in no other way, concerning two important particulars: (1) The grade of intestinal distention and the location of the distended coils, and (2) whether free gas is present in the peritoneal cavity.

In the study of suspected acute small bowel obstruction, very early objection was raised to the employment of bismuth or barium for fear of hastening the development of a complete obstruction. Some surgeons even protested against the use of barium for the study of the colon by the retrograde method, fearing an impaction might bring on an acute obstruction, and they recommended the use of a solution of sodium iodide. Case, beginning in 1912, had used barium sulfate routinely to supplement survey roentgenograms of the abdomen in the study of suspected ileus but in later years to meet objections to the insoluble heavy salts he recognized the value of the aqueous solution of thorium dioxide (umbrathor) and has used it in place of barium sulfate for the study of suspected ileus for the last eighteen years. Umbrathor, being an aqueous solution of thorium dioxide, remains fluid and presents no possibility of impaction above a stricture.

The present-day recommended technique for the study of a case of suspected acute intestinal obstruction should include (1) survey roentgenograms of the abdomen, in the erect position if possible; if not, with the patient lying on the side as well as supine; (2) the immediate administration of umbrathor when one first suspects the obstruction so that in case of delay in reaching a decision more definite visualization will result when the harmless umbrathor finds its way down the bowel to the site of the obstruction; (3) intubation if the attending physician dares to delay action for the use of the Miller-Abbott tube for decompression. Further studies may be made by introducing umbrathor through the tube into the intestine. One serious danger which always must be recognized when one employs intestinal intubation in the diagnosis or treatment of acute intestinal obstruction is that the obstruction may be mechanical and that delay in operation may result in fatal gangrene of the bowel.

Postoperative adhesions, intussusception and volvulus have been variously reported on, but gallstone ileus deserves special mention. Borman and Rigler[24] (1937) pointed out that gallstone ileus is suggested when in the presence of ileus one finds air in the biliary passages, the air having reached the biliary tract through the internal biliary fistula which gave passage to the gallstone when it found its way into the intestine.

Diverticula of the duodenum were first described roentgenologically by Case[52] and by Forssell and Key[89] in 1913. Jejunoileal diverticula were first reported as discovered in roentgen studies by Case,[53] who in 1920 summarized his work of ten years. Contemporary valuable contributions were made by Cole and others,[73] and Roberts[188] and later by Stetten.[204]

Tuberculosis of the small intestine was early studied by many, including Stierlin,[208,209] whose "vacant space" came to be known as Stierlin's sign but which later was shown to be present not only in tuberculosis of the ileocecal region but also in other ulcerative intestinal lesions. Carman[32,33] wrote several important papers on the subject. Other prominent contributors were Brown and Sampson,[27] Gershon-Cohen,[97,98] Sussman,[213] and Weber.[223]

Carcinoma of the small intestine was an occasional diagnosis from the time of the earliest employment of the contrast meal, and occasional attention has been given to tumors of the intestine, benign and malignant, by authors too numerous to mention. Within the last ten years renewed interest has been injected into the effort to make more definite the evidence of carcinoma

and other tumors of the small intestine by the employment of the intubation technique popularized by a series of studies by members of the staff of the Department of Radiology, University of Pennsylvania, and associates in other clinical departments including Abbott and Pendergrass,[2] Pendergrass *et al.*,[170] Miller and Abbott,[157] and possibly others. Many of these studies were based on intestinal intubation.

Crohn, Ginzburg and Oppenheimer[80] first described regional ileitis in 1932, concluding that it was a pathological and clinical entity. Homans and Hass[126] in 1933 took issue with this idea, however, and insisted that regional ileitis was a clinical and not a pathological entity. Numerous publications on this subject have appeared inthe literature, including that by Kantor,[137] on the roentgen diagnosis. The original concept of Crohn with various modifications has been generally accepted.

The crowning contribution to roentgenology of the small intestine is the recent book by Golden[104] which summarizes the newer advances in roentgenology of the small bowel, and gives a very complete discussion of the roentgen evidences of disturbances of nutrition, allergic reactions, physiologic behavior of the jejuno-ileum in response to various foods and drugs, and an especially interesting analysis of the roentgen evidence in the so-called deficiency states. Golden summed up his own observations as well as those of Mackie, Miller and Rhoads,[150] Mackie and Pound,[151] Gershon-Cohen, Weber, and many others.

Prior to 1924 the study of the gallbladder was conducted by the use of simple roentgenograms and by studies in which the ordinary roentgenograms were supplemented by the injection of air or of opaque material into the stomach and duodenum and the colon. Carl Beck[13,14,15] (1898) was the first to publish roentgenograms of gallstones in the living, including 2 cases in a report before the New York County Medical Association in December, 1899. As McCoy[153] later pointed out, there is some doubt as to the correctness of his diagnosis in these first 2 cases, but Beck did a great service to roentgenology in insisting on a number of technical factors to be observed in the exposure of the plates and in their interpretation. He also published a case of transposition of the viscera with a gallstone on the left side. Occasional cases of roentgenological demonstration of gallstones were also published by Köhler[14] (1904), Holland,[120] Matthias and Fett[152] (1905), and in 1910 at the meeting of the American Roentgen Ray Society in Detroit, Pfahler,[173,174] Haenisch[173] and Cole[173] each contributed reports on 3 cases. Case[42,43] (1913) was the first to report the demonstration of gallstones in a considerable number of individuals, finding gallstones in 40 cases in a series of 1,000 routine gastrointestinal examinations and in 8 others. George and Gerber[93] (1914) considered that the roentgen findings in disease of the gallbladder were so common that they would in future include the gallbladder area in all gastrointestinal studies. Holland,[121] Pfahler,[177] and Cole[70,71] again wrote on the subject as did Case,[51] George,[94] Knox,[142] Groedel,[111] Palmer[168] and others. Haenisch[114] in 1924 published a monograph on the roentgenologic investigation of the liver, the gallbladder and gallstones, in which he said he was stimulated by the American literature to make an intensive study and to give to his German colleagues the assurance that the subject deserved more attention than they had previously given to it. Case[42] in 1913 had estimated that it was possible to show gallstones roentgenographically in about 40 per cent of the cases in which they were present, the percentage depending, of course, on the number containing lime salts in sufficient proportion to show on the roentgenograms. In 1923 Carman[34] reported from the Mayo Clinic on 226 cases in which gallstones were found at operation, and stated that 38.4 per cent were previously diagnosed by roentgen study (very close to the figure estimated by Case ten years before). Carman emphasized the already expressed general opinion that a negative report of

gallstones on the survey roentgenograms of this region was worthless.

A new era of gallbladder diagnosis dawned when Graham and Cole,[106,107,108] assisted by Copher and Moore, introduced a new method of gallbladder diagnosis utilizing the intravenous injection of tetrabromphenolphthalein. This method was developed after patient experimental work based on the evidence of Abel and Rowntree[3] that the phenolphthaleins as a class were largely excreted in the bile. Graham and his associates applied the name "cholecystography" to the visualization of the gallbladder with tetrabromphenolphthalein (later employing the sodium instead of the bromine salt), and the exposed roentgen films were called "cholecystograms."

Menees and Robinson[154] demonstrated the feasibility of the oral administration of the gallbladder dye. After a number of years of both intravenous and oral administration of the dye by various investigators, the idea of fractionating the gallbladder dye for oral use was the final advance needed for the oral method to almost completely supplant the intravenous administration of the phthalein compounds in gallbladder diagnosis.

On a series of more than 500 cases studied with intravenous cholecystography and later checked by surgery on the gallbladder, Case[61,62] was able to state that in 75 per cent of cases where the gallbladder failed to visualize ("absence of shadow") the probability of gallstones was 75 per cent; another 15 per cent were found to show gross gallbladder disease without stone, and 10 per cent of the cases showed extracholecystic biliary tract disease. The error on the series of 106 cases showing "absence of shadow" or failure to visualize was only 3 per cent; that is, only 3 cases were found at operation to be normal. His later experience with the divided oral doses gave equally accurate results. It followed from his statistical study (borne out by further check on operated cases) that if gallstones were shown by cholecystography, the diagnosis was almost certain; with failure of visualization there was 75 per cent chance of stones; if no gallstones were found in a gallbladder which was at all visualized, stones could be excluded with 95 per cent surety.

Other important contributions relative to cholecystography include that of Carman[35,36,37] and of Kirklin[139] and associates on cholecystography in general, and in particular that of Kirklin on tumors of the gallbladder,[140,141] Stewart and Ryan[206] on the advantages of division of the dose of the dye for cholecystography, Whitaker and Milliken[226] and Sosman *et al.*[201] on the influence of various foods on the emptying of the gallbladder after visualization with dye. Today cholecystography stands on a firm foundation as one of the most reliable tests of cholecystic disease and for estimating the motor function of the gallbladder. It is nowadays a rare event for a patient to be sent to surgery for the gallbladder in the face of normal cholecystographic findings.

Ever since the early days of roentgenology, especially since the work of Emil Beck[16] on the visualization of fistulous tracts with bismuth paste, biliary fistulae have been studied with the roentgen rays after the injection of some form of opaque material, but this type of examination was not systematically employed or productive of important diagnostic aid until Tenny and Patterson[216] injected bile ducts with bismuth paste and made observations on the flow of bile. Cotte[75,76] Walzell,[219] Ginzburg and Benjamin,[100] Judd and Phillips,[134] Kretchmar,[144] among others, introduced various opaque media, such as iodipin, umbrathor, thorotrast and hippuran and other preparations used for excretion urography, into biliary fistulae or through a T-tube. This method permitted not only the recognition of common duct stones but also common duct strictures, and assisted in the decision as to when the T-tube might be removed.

Mirizzi,[160,161,162] of Cordoba, Argentina, is credited with being the first (1932) to sug-

gest cholangiography during operation. Saralegui[193] (1935), of Buenos Aires, added much from his personal experience. Hicken Best and Hunt[118] made important contributions to the direct roentgen visualization of the biliary tree during operation to determine whether the ductal system is patent or obstructed, the position and number of calculi, the extent and location of stenotic lesions, the function of the sphincter of Oddi, also to outline communicating fistulae and to visualize dilatation and sacculation of the common duct. The injection of the biliary tract may be done immediately during the course of and as a part of the surgical procedure, or it may be done later through tubes left at operation or through fistula. Thorotrast is perhaps the best opaque medium for this purpose, though many have found lipiodine satisfactory. A contribution by Bettman, Tannenbaum and Arens[23] advocating immediate cholangiography in the operating room when there is the slightest suspicion that a stone may be present in the common duct has further stimulated interest in this valuable means of avoiding sins of omission in surgery of the biliary passages. Many hospitals are now equipped for the employment of cholangiography at the tableside in surgery of the biliary tract.

The study of the liver was begun very early in the roentgen era by the introduction of air or gas into the stomach and colon to estimate the size of the liver. Béclère[18] in 1911 described a method of orthodiagraphic examination of the liver, permitting the exact measurement of its diameters. As average figures for the normal, he gave the extreme transverse diameter of the liver as 28 cm., the anteroposterior 17 cm., and the vertical diameter as 8 cm. Pfahler[178] in 1926 also described the measurement of the liver by means of the roentgen ray in a contribution based on a study of 502 subjects. The behavior of the liver in cases of subphrenic and of intrahepatic abscess was carefully investigated and reported on by many writers. Hydatid cysts of the liver usually show some calcium in the walls of the cysts which permit their recognition.

Metastatic nodules of malignant disease in the liver were difficult of demonstration until the introduction of hepatolienography (hepatosplenography). The intravenous injection of thorotrast for visualization of the liver and spleen was introduced by Oka[165] and by Radt,[180] based on the tendency of this compound to be deposited in the reticulo-endothelial cells. The procedure was applied to the localization of tumors suspected of being located in the liver or spleen, to the diagnosis of cirrhosis of the liver and the recognition of abscesses, cysts, amyloidosis and other tumors, and particularly for the demonstration of metastatic invasion of the liver by malignant disease. Kadrnka,[135] Stewart, Einhorn and Illick[207] and Yater and Otell[228] made use of the method, the latter authors finding it very helpful. But serious theoretical objections to the use of thorotrast were made by a number of clinicians, and the Council on Pharmacy and Chemistry of the American Medical Association voted that thorotrast be not accepted for intravenous administration because of the very imperfect elimination of the thorium dioxide, its fairly high alpha-ray activity, and the possibility of further increase in its radioactivity by partial conversion to mesothorium and radiothorium. Because of these possible latent dangers, the method was not recommended and only lately has it begun to regain some of its former popularity. This has occurred in spite of the experimental work which indicated potential menace as reported by Taft,[214] on the one hand, though, on the other hand, clinicians have not reported any serious ill effects. Rigler, Koucky and Abraham[186] in 1935 reported on the effects of thorium dioxide sol on the human liver, following up 180 patients of whom 22 had had the solution injected one, two or three years before without any untoward results. Reeves and Apple[181] in 1933 had advised the use of thorium dioxide sol (thorotrast) in the diagnosis of liver abscess. Again in 1936, in reiterating the

value of thorotrast hepatosplenography in liver abscess, Reeves[182] stated that in an experience of seven years he had not observed any ill effects in any of his patients. Yater[229] and his colleagues in 1936, later in 1938, and finally Yater and Coe[230] in 1943, reporting on ten years' experience with hepatosplenography, were unable to find evidence that thorotrast has contributed to the death of any of 64 patients whose spleens and livers were studied with microscopic section after operation and death. Though 286 patients were followed over a period of more than ten years, no immediate or remote ill effects of importance were discovered. There was no evidence of latent radioactivity, depression of hepatic or splenic or hematopoietic function, lowered resistance to infection or development of malignant neoplasia at the site of injection. This method of hepatosplenography or hepatolienography continues to be of definite value in the diagnosis of cirrhosis of the liver, to determine the presence of metastases in the liver, and in the diagnosis of abscess of the liver. It seems that a concession may be made to the experimental results by reducing the amount of thorotrast injected, depending on improvements in roentgenographic technique to compensate for the diminished density of the hepatic shadows.

I am keenly aware of the sketchiness of the foregoing account of the evolution and present value of roentgenologic aid in the practice of gastroenterology. In spite of the fact that this review and its bibliography seem overly long, it is realized that many names of well known pioneers in American radiology whose work included contributions to gastroenterology have been omitted. This is much regretted. Apologies are extended to any who may feel that their work should have been mentioned. Much space could have been devoted to various gastroduodenal lesions and to anomalies, such as congenital shortening of the esophagus. European references have been given with no attempt to include all, even of the important contributors. Advances in the design and manufacture of roentgenologic equipment have added much to the onward march of the clinical use of the roentgen rays.

We dedicate our efforts to the future of gastrointestinal roentgenology with confidence that the emphasis will be placed on close cooperation between the radiologist and the referring physician.

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ROENTGEN DIAGNOSIS IN UROLOGIC DISORDERS

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THE discovery of the x-rays by Wilhelm Conrad Röntgen in 1895 probably contributed more to urology than to any other branch of medicine. Previous urologic diagnoses were founded on evaluation of urinalyses and palpable masses in the abdomen, often difficult or impossible to associate or dissociate with urinary tract lesions. This was particularly true of those of the kidney because of the wide variation in kidney position. Bladder stones could be identified only by sounds or stone searchers.

The difficulty in urologic diagnosis and the slow development of urology may be illustrated by the following facts:

Perhaps the earliest mention of urologic diagnosis is in Egyptian writings of 3000 to 1150 B.C. The instruments used were bronze and imported tin knives, catheters,

FIG. 1. Male, aged forty, complained of back pain and hematuria for seven weeks. Three years ago he passed calculi with hematuria. Roentgenogram of the kidney region showed no suggestive urinary tract shadows. A pyelogram revealed a rather large non-opaque stone in the left kidney pelvis. Cystoscopic examination showed blood coming from the left ureter. A large calculus was removed at operation. This case illustrates the importance of pyelography when calculi are suspected, even if the roentgenogram of the urinary tract is normal.

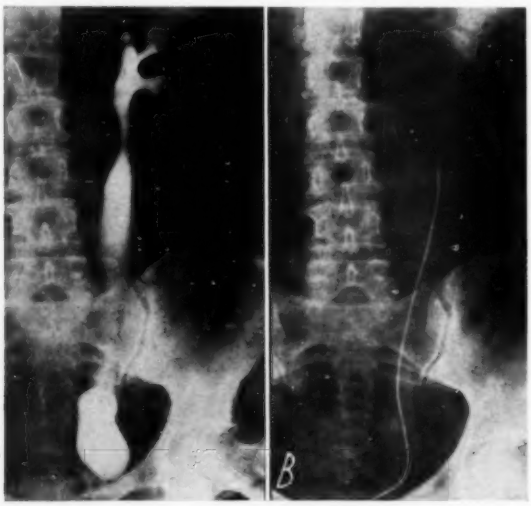
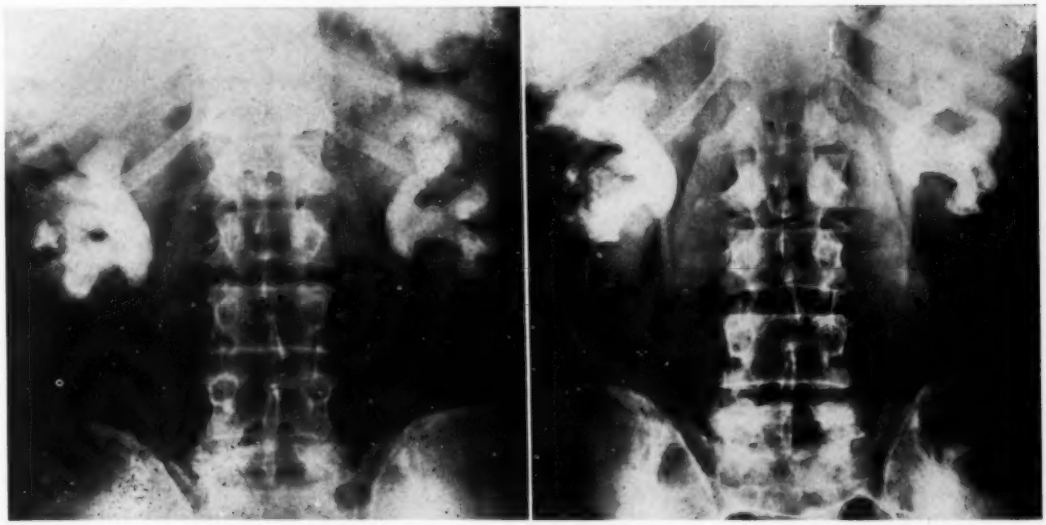


FIG. 2. Female, aged sixty, had frequency, pain, cystitis, and distress since 1910, when she was in bed for a month. Roentgenogram of the kidney region suggested a calcification in lower left ureteral area. Pyelogram showed large dilated left ureter (*A*). Kidney pelvis and calices appeared to be essentially normal. A large dense calcific deposit in the lower left ureter was believed to produce intermittent obstruction in the ureter and the patient's pain (*B*). Stone was not in contact with the catheter placed in the ureter so that it could be missed without a pyelogram. Previously, such a stone could not be palpated or felt by a catheter, particularly a wax-tipped catheter, or even by a sound. Now with opaque medium in the ureter, so-called ball-valve stones may be apprehended whether or not in contact with a catheter or other instrument introduced into the ureter. A left ureteronephrectomy eliminated the patient's symptoms.



A B

Fig. 3. Male, aged fifty-nine, had a left renal calculus for ten years, intermittent colic, hematuria, and hypertension. During the past year a calculus developed in the right kidney. Roentgenogram of the urinary tract showed a large staghorn calculus in each kidney (*A*). Urogram visualized both ureters with no obstruction or retention on either side (*B*). Bladder was normal and the renal function exceedingly good. The determination of function and dynamics of the ureter is of great importance in the treatment of calculi and is usually best done by excretory urography.

and sounds. Susruta, ancient Hindu medical authority, mentioned in 1000 B.C. various gold, iron, and wood tubes for urethral dilation. For centuries only such devices, particularly sounds, were available to men attempting to diagnose stones or strictures.

In his "Confessions" Jean Jacques Rousseau (1712–1778) described his personal experience with the diagnosis of calculi:

> Perceiving my suffering to be incessant, M. D. Luxembourg sent for Friar Come. The operation was cruel, indeed. Come thought he found a great stone. At the second examination he could not find it again. After a third examination with so much care and circumspection that I thought the time long, he declared there was no stone, but that the prostate gland was scirrhous and thickened. He added that I had a great deal to suffer and should live a long time.

Many centuries later men were still depending for location of a bladder stone upon the click of the calculus against a metal in-

Fig. 4. Female, aged thirty, complained of frequency. Bladder polyp was fulgurated seven weeks prior to examination. Fifteen years ago heminephrectomy was done for tuberculosis of the right kidney. Roentgen examination of the urinary tract showed extensive calcification, demonstrating tuberculosis of the right kidney with a closed ureter making an autonephrectomy. Right and left ureter also showed calcification. Excretory urogram revealed

no function on the right, a large infected left hydronephrosis probably due to tuberculosis, and apparent vesical tuberculosis.

FIG. 5. Female, aged twenty-nine, had hypertension with a systolic pressure of 200 mm. of mercury and a diastolic pressure of 122, for which she had every type of examination except investigation of urinary tract. Family history was negative. A left celiac ganglionectomy was done without beneficial result. Bilateral pyelograms showed a right duplex kidney, a left duplex kidney, two right ureters extending to the bladder, and the left ureter bifurcated about midway.

Pyelogram showed dilatation of the branch of the left ureter going to the upper calix which was somewhat blunted indicating partial obstruction at the point of bifurcation. This suggested a possible cause for the patient's hypertension. The lower half of the kidney was normal. The patient died from cerebral hemorrhage in about six months. Dr. Crile's comment was: "The rapid progress of this case showed that there was little hope for relief of hypertension by adrenal sympathectomy in a hypertension due to nephritis."

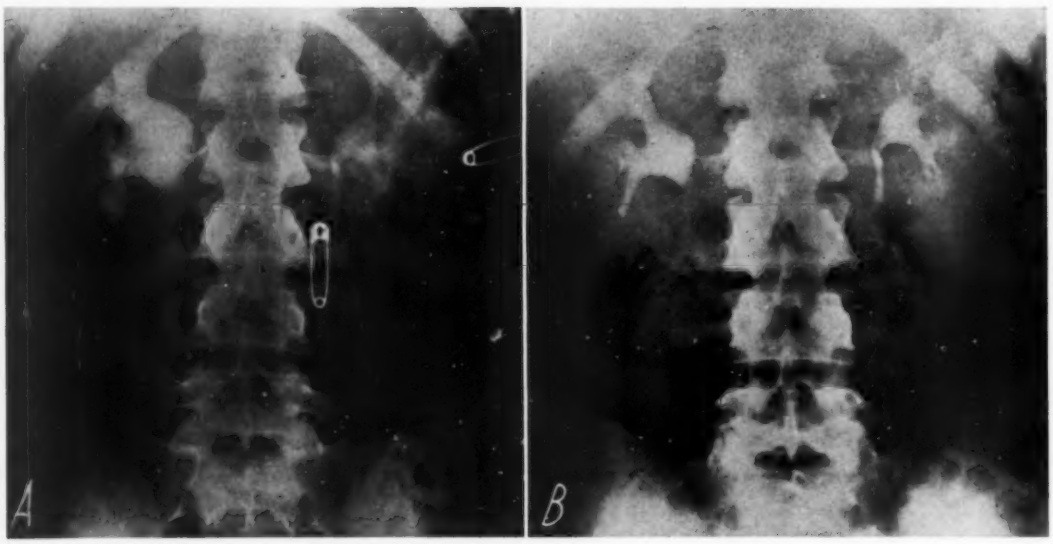


FIG. 6. Female, aged twenty-two, had contracted urinary bladder with symptoms since childhood. She had a cystoscopic examination, and Hunner ulcer was cauterized. Ureteral transplant was suggested. Both ureters were transplanted into the sigmoid. Urogram done before operation showed both kidneys to be normal. Excretory urogram done seventeen days after operation revealed a normal left kidney and ureter (*A*). From dilatation and hydronephrosis the right kidney was about twice the size of the left.

Excretory urogram a year later revealed normal kidneys with good function on both sides (*B*). This case illustrates the possibility of a temporary hydronephrosis after ureteral transplant and a return to normal after relief of temporary obstruction at the point of junction. Only by urography can such information be obtained.

strument, and until the advent of direct visualization, little was added during these centuries to methods of urologic diagnosis.

Then, early in 1896, the world was astounded at the announcement of the discovery of the x-rays by Wilhelm Conrad Röntgen, and the urologist acquired a new aid to urologic diagnosis. Development of this science, however, was severely handicapped by lack of progress in the manufacture of tubes and other equipment.

The urinary tract was first made visible or opaque to roentgen rays by Tuffier[12] in 1897. He introduced an opaque ureteral catheter into the urinary tract and then made a roentgenogram. Apparently, however, this method was not actually demonstrated until 1901, when Schmidt and Kolischer[9] published roentgenograms with catheters in the ureters. Later observers used bougies impregnated with metal.

Keyes,[6] writing in 1903, made the following comment:

Fig. 7. Female, aged twenty-five, complained of pain in the back for five years. At the time of pain patient had some fever and chills. She had no weight loss. A normal pregnancy two years prior to examination had been complicated only by chills. Pyelogram revealed a fused kidney with three separate divisions and bifurcation of the left half, which showed extensive hydronephrosis. Operation revealed a large globular mass (lemon-size) on the left. Turbid urine was expelled into the wound after the sac was excised. The sac was resected from the normal tissue of the left kidney, and the stump was ligated. The pyelogram made possible the diagnosis and elimination of the patient's symptoms.

Fig. 8. Female, aged forty-nine, complained of pruritus ani. A palpable mass, thought to be a kidney, was felt in the upper right portion of the abdomen. For years patient had frequency, occasional burning on urination, and some nocturia.

Urogram showed a large globular enlargement of the lower pole of the right kidney, compressing the lower portion of the kidney pelvis and displacing the ureter toward the midline. Upper calices appeared normal and showed prompt function. Operation was performed, and a large solitary cyst (orange-size) of the lower pole of the right kidney was resected. Ten years later the cyst had not recurred, and a well functioning kidney was present. Primary diagnosis was made by palpation of a mass and confirmed by a urogram.

FIG. 9. Female, aged twenty-one, complained of pain in the right side, inability to straighten right leg, weight loss, weakness, nocturia, and frequency. Temperature was 102.5° F. Duration of symptoms was six weeks. Twenty-four hours before examination symptoms became worse. Palpation suggested mass in right kidney region. Roentgenogram of the urinary tract showed a mass at lower pole of right kidney, left scoliosis, and loss of right psoas muscle border (*A*). Roentgenogram on deep breathing showed no movement of right kidney, whereas downward excursion of left kidney was normal.

Pyelogram showed normal left kidney. Right kidney was deformed by a mass extrinsic to the outer lower pole (*B*). These findings suggested perinephritic abscess. After drainage, injection of bismuth paste into the fistulous tract showed extension of the abscess through the retroperitoneal area (*C*). This was a tuberculous infection. Kidney excursion may be demonstrated by double exposure of a film of the urinary tract; one on inhalation and one on exhalation.

FIG. 10. Male, aged forty-nine, gave a history of acute colic and hematuria. A calculus was suspected in the left kidney. Pyelogram of the left kidney showed pronounced dilatation of the extreme lower minor calix with some indistinctness of the outline of the wall (*A*). Impression was early renal tuberculosis. Urinalysis showed no tubercle bacilli.

Eleven months later the patient complained of continued intermittent hematuria and pain in the left upper portion of the abdomen. Pyelogram showed normal right kidney, filling defect in the left kidney or absence of lower calix, and a narrowing at ureteropelvic junction (*B*). Impression was either tuberculosis or neoplasm in the lower calix. Nephrectomy showed papillary carcinoma of the lower pole of the left kidney.

The patient was seen two years later in good health. Roentgenograms of two recent cystoscopic examinations showed normal right kidney with a compensatory hypertrophy (*C*). There was no evidence of recurrence of another kidney lesion, or of metastasis. Patient had been free from urologic symptoms for thirteen years.

"Radiograph is useful in all cases and tells the surgeon where to look for calculi and relieves him of responsibility as to the presence of additional calculi in the ureter or kidney, which might be difficult to locate in the course of operation."

Fig. 11. Female, aged sixty-five, had pain in the upper portion of the abdomen. Clinical impression was questionable splenomegaly. Abdominal examination revealed large, freely movable, soft mass extending from upper left quadrant to umbilicus. There was tenderness over the mass. Urine was normal; leukocytes 7,800; hemoglobin 71 per cent; erythrocytes 4,110,000. Roentgenogram of the urinary tract revealed no suggestive urinary tract shadows. Right kidney was normal; left kidney was large.

Urogram showed prompt function of both kidneys. The right kidney appeared normal. There was no obstruction. A large tumor mass occupied the upper pole of the left kidney, which was displaced downward with marked compression of the pelvis. Total renal function was below normal. Impression was large hypernephroma of the left kidney. Survey for metastasis revealed none in the bones or chest. Roentgen therapy was given daily for one month, alternating anterior and posterior fields every other day. The patient died after six months.

This case illustrates the necessity of early diagnosis of kidney tumor, which is often first suggested by an abdominal mass, and which may be confirmed by urogram or pyelogram. In less than half the cases of hypernephroma does bleeding or other urinary symptoms appear until late in the disease. Excretory urography will often disclose such a lesion in an early state, thereby offering through surgery the only hope of cure.

Fig. 12. Female, aged thirty-six, had headaches and irregular menstrual periods. She had diabetes mellitus and hirsutism of upper lip, chin, cheek, and arms. Impression was hyperadrenalism and possible adrenal tumor. Routine roentgen examination did not show enlargement of adrenal glands or presence of tumor. Air injection revealed the kidneys and adrenal glands to be free from tumor and about normal in size.

Roentgen examination after the introduction of air perirenally made it possible to rule out the adrenals as a cause of symptoms. This illustration shows visualization of the right adrenal.

Next, an attempt was made to visualize the urinary tract by opaque media. Klose,[6] who had been using bismuth to visualize the gastrointestinal tract, introduced an emulsion of bismuth into the pelvis and ureter. The contrast, however, was not sufficient for diagnostic purposes. Not until 1906, about ten years after the discovery of the roentgen ray, was the urinary tract successfully visualized. Using a 5 per cent solution of colloidal silver, Voelcker and Lichtenberg[13] made the first satisfactory pyelogram.

They clearly demonstrated the value of

FIG. 13. Female, aged sixty-three, complained of attacks of pain in the lumbar region radiating to the lower abdomen, burning at the neck of the bladder, nocturia, and frequency. Previous cystoscopy showed a non-functioning left kidney and poorly functioning right kidney. Urinalysis was essentially normal. Cystoscopic examination showed trigonitis. A pyelogram showed multiple congenital ureteral cysts. A left nephrectomy was done, and the pathologic report revealed atrophy and fibrosis, hydronephrosis, some stenosis at the ureteropelvic junction, and multiple ureteral cysts. It would have been impossible to make this diagnosis without urography.

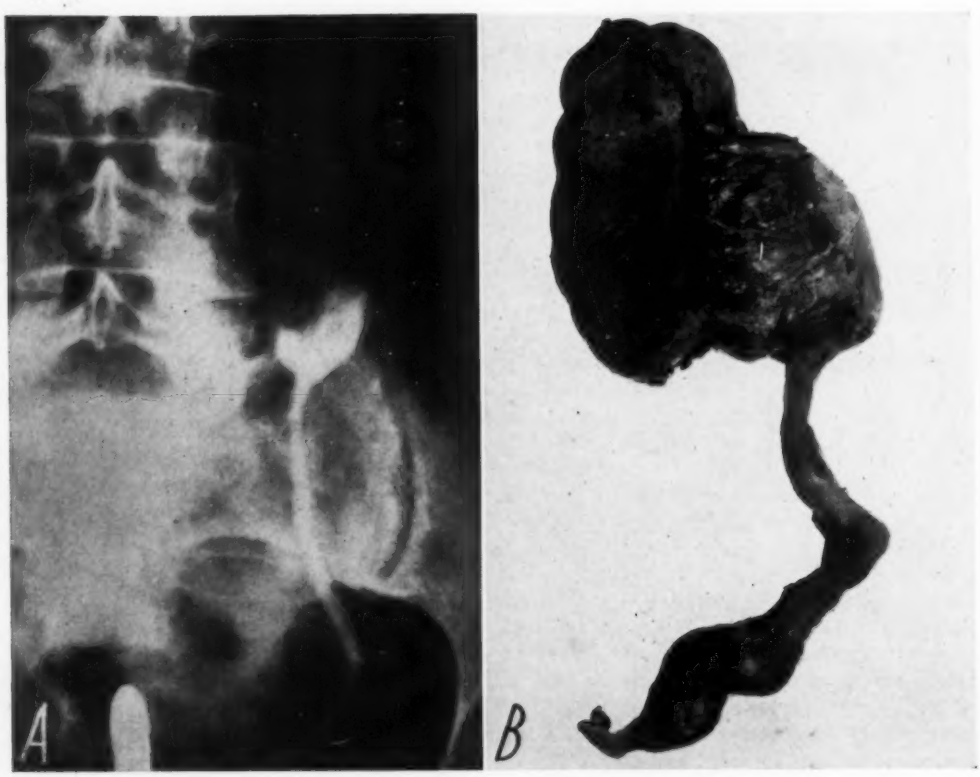


FIG. 14. Male, aged sixty, had occasional hematuria and weight loss of 25 pounds for one year. Six months prior to examination, clots obstructed the urethra. Cystoscopic examination was normal. Right ureter was catheterized with difficulty. By ureterogram a tumor of the ureter was located (*A*). The ureter and kidney were removed. *B* shows specimen, a primary carcinoma of the ureter.

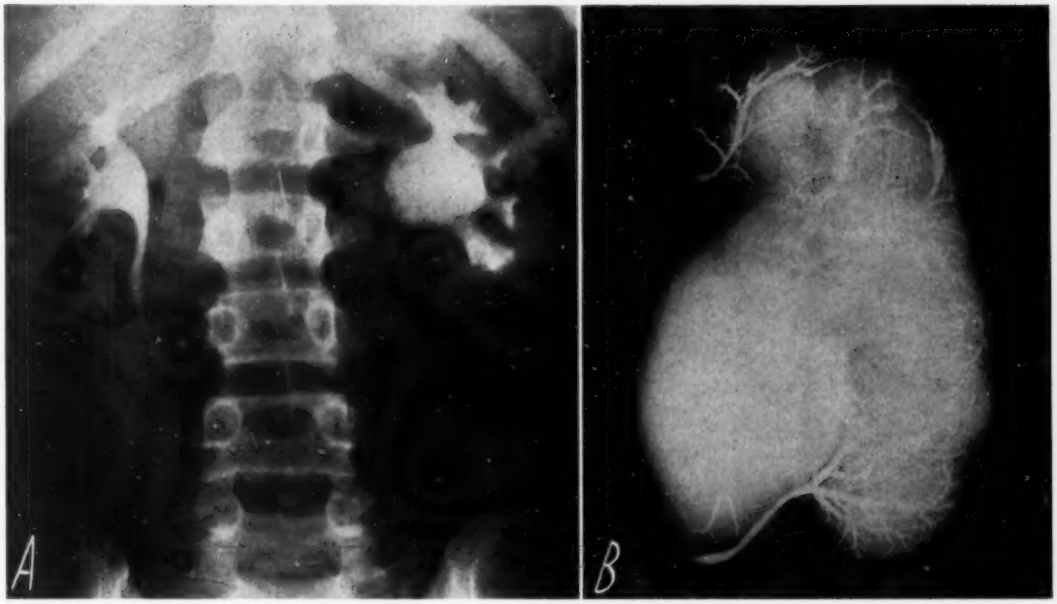


Fig. 15. Male, aged thirteen. Diagnosis was left hydronephrosis due to aberrant vessel at lower pole (*A*). Roentgen examination, particularly an excretory urogram, made possible early detection. So often when this condition occurs on the right side, the patient is operated upon for appendicitis, gallbladder disease, or duodenal ulcer before a correct diagnosis is made. Or when it occurs on the left side, intestinal obstruction or another lesion is often first suspected before the kidney is examined.

The injected specimen illustrates the course of the aberrant vessel which produced the intermittent obstruction of the upper ureter with secondary hydronephrosis (*B*). In undiagnosed cases such a condition often results in complete destruction of the kidney before proper surgical treatment is instigated.

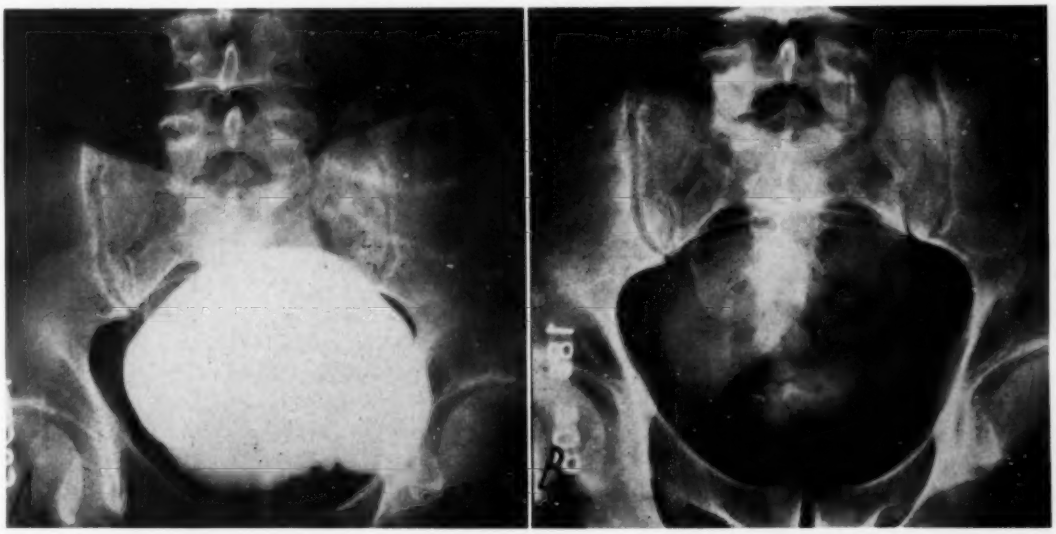
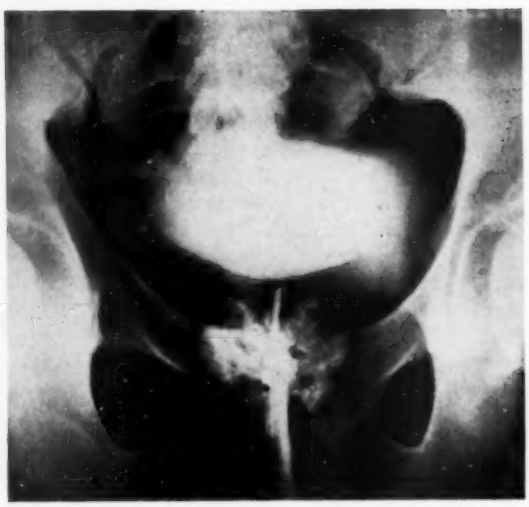


Fig. 16. Male, aged thirty-two, had frequency, burning on urination, and tenderness over the abdomen from symphysis to umbilicus. Prostate was indurated but of normal size. Cystogram showed large diverticulum in right anterior bladder quadrant with slight retention (*A*). The lower portion of the bladder was somewhat irregular. Urogram showed moderate hydronephrosis and dilatation of the lower left ureter (*B*). Impression was a large diverticulum of the bladder in the right upper quadrant and a bladder tumor. Total kidney function was good. Because the lesion was so extensive, a transurethral resection was done and radium implanted. Patient died three months after first examination of inoperable carcinoma of the bladder.

This case illustrates the possibility of overlooking even large bladder lesions if only a cystogram is made, particularly if no roentgenogram is made after emptying the bladder.

FIG. 17. Visualization of seminal vesicles is often of great diagnostic importance. The seminal vesicles are catheterized and an opaque medium injected into them. A seminal vesiculogram is illustrated in this figure.

A



B

FIG. 18. In 1941 Trattner[11] made a preliminary report on the injection of the prostate gland with a partition catheter which makes possible visualization of the tubulo-alveolar units. The prostate gland on rare occasions had been visualized, particularly during a ureterogram, in patients who had abscesses from fistulous tracts or even a large anatomic orifice. Trattner's catheter with its two balloons, one for closure of the vesical neck and the other for blockage of the distal urethra, makes it possible to isolate the prostatic area from the rest of the urethra and from the bladder, and to introduce and retain fluid in the partitioned portion. By introduction of solutions into the tubulo-alveolar area of the prostate, roentgen visualization may be accomplished. The author uses diodrast solution of 50 to 75 per cent.

The following conditions may be determined by this method of examination: presence of a normal prostate, enlargement of the ducts, cavitation from abscess, presence of a cyst, obstruction of a duct by stone, prostatic hypertrophy with inflammation or interstitial fibrosis. In addition, a diverticulum or a fistula in the prostatic urethra may be visualized.

Excessive pressure during injection or an excessive amount of opaque medium may produce extravasation into the prostatic tissue and should be avoided. *A* shows a normal prostate, *B* shows abscess of the left side of the prostate.

This method of examining the prostate, one of the latest developments in urology, makes possible the diagnosis and treatment of certain pathologic conditions in the prostate gland (Fig. 18, *A* and *B*, courtesy of Trattner.[11])

pyelography in the diagnosis of hydronephrosis and suggested the possibility of its value in tumors. Many other observers followed with the diagnosis of numerous pathologic conditions in the urinary tract.

In 1911 Lichtenberg and Dietlen[7] reported a series of pyelograms after the introduction of oxygen into the urinary tract. Many attempts were made to obtain a satisfactory medium by improvement of silver salts. Notably, Braasch[3] in 1913 recommended that colloid silver crystals be pulverized, dissolved in lukewarm water, and carefully filtered.

Many attempts were also made to aid in filling of the ureters by changes in the patient's position, such as the erect and the moderate Trendelenburg position.

Braasch[2] in 1912 called attention to the value of pyelography in the diagnosis of renal tuberculosis and in the accurate location of many of the more important urinary tract lesions. He also contributed greatly to the interpretation of inflammatory changes in the kidney by the use of pyelography.

Some fatalities from pyelography were observed by various urologists and roentgenologists. The available media in the early days seemed to be the most important problem. Braasch[4] in 1915 in reporting 1,000 pyelograms made the following comment:

> Efforts should be made to discover a substance which will not injure the kidney, under any circumstances, and which may be safely employed in the hands of those with limited experience.

Bilateral pyelograms made with sodium iodide were often considered unsafe, but not until 1929 was this medium improved. Then Rowntree[8] and his co-workers demonstrated the possibility of excretory urography with the intravenous use of sodium iodide, although this medium was not sufficiently concentrated in the kidney for any practicable purpose. About this time, Binz[1] in Berlin was studying the selectan drugs. This came to the notice of Lichtenberg. He selected one preparation secreted by the kidney and with the aid of one of his associates, Swick,[10] accomplished an alternation in the No. 9 group of the drug selectan and found duroselectan to be of sufficient concentration and nontoxicity for practical use. Thus, uroselectan came into being. This was the beginning of intravenous urography.

In 1930 with Dr. William E. Lower I saw a demonstration by Swick of excretory urography in Dr. Leopold Jaches' laboratory in Mount Sinai Hospital, New York. Since that time, however, new combinations have become very satisfactory for excretory urography. By use of uroselectan many examinations are possible that could not previously be done by pyelography: the study of the urinary tract during pregnancy; the examination of the urinary tract in children, which may be accomplished by injecting the medium subcutaneously; the study of the kidneys and ureters in patients after transplantation of the ureters into the rectosigmoid; when prostate hypertrophy or lesions in the bladder preclude cystoscopy.

It is impossible in this contribution to refer to all of the urologists and roentgenologists, of whom there were many, whose untiring labors and contributions made possible the present status of roentgenology in urology.

In the accompanying illustrations and case histories are described a few practical applications of the roentgen ray in urology. These draw attention to the high tribute due Wilhelm Conrad Röntgen, who by his labors and perspicacity made urology one of the great specialties of medicine.

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BACKGROUND AND BEGINNING OF CHOLECYSTOGRAPHY

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FOR almost thirty years the history of the roentgenology of the gallbladder was that of a constant purpose scantily fulfilled but tenaciously maintained in the face of difficulties. The record is marked by trial and error, by fresh hopes and new disappointments, by fruitless efforts and partial successes, all alternating with long periods of apparent stasis. Yet through all these years the real or fancied progress was sufficient to encourage persistence in the original design and inspire the renewed endeavor that led to an epochal advance. Indeed, it might reasonably be contended that the present highly developed art is wholly the product of the unswerving aim and persevering will of men. But whether it represents a purely human triumph, a natural outgrowth in the evolution of medicine or an inevitable resultant of fortuitous forces, physician and patient alike have reason to be glad that it exists.

When the roentgen rays were first presented to a marveling world late in 1895, the first thought was of their potential application to medicine, and this thought was further stimulated by Röntgen's depiction of his wife's hand. Roentgenographic revelation of bones was quickly followed by the demonstration of foreign bodies. Then concretions in the human body came into consideration. Gallstones that had been removed were subjected to roentgenography by various investigators and it was quickly learned that gallstones containing calcium cast appreciable shadows but that stones composed of cholesterol could scarcely be depicted. Early in 1897, little more than a year after Röntgen's discovery was announced, Buxbaum,[3] of Vienna, succeeded in securing shadows of gallstones in 4 of more than 30 patients examined. In 1900 an American, Beck,[2] was similarly successful in 2 cases. For more than a decade longer, roentgenologic examination of the gallbladder was confined to searching for shadows of gallstones. Apparatus was crude, gas tubes were fickle and demonstrations of the shadows were disappointingly rare.

Meantime, the examination of the alimentary canal with opaque media was developing rapidly, and in 1910 Schürmayer,[9] followed later by others, directed efforts toward the indirect diagnosis of cholecystic disease by disclosing signs of pericholecystic adhesions, such as fixation, displacement or deformity of the pyloric end of the stomach, the duodenum or the hepatic flexure of the colon. Other investigators pursued this method of approach and, although its results were not often fruitful, it served at least to stimulate interest in the entire problem. During the succeeding period came the development of the interrupterless transformer and of the Coolidge tube, inventions that facilitated all roentgenologic examinations, and study of the gallbladder received increasing attention. In 1917 George and Leonard[4] announced that in certain instances they had been able to produce and distinguish a shadow of the gallbladder when neither gallstones nor deposits of calcium were present. Further, they assumed, as a working hypothesis, that only when some pathologic change had taken place in the walls of the gallbladder or its contents would its shadow be depicted. To secure and discern the shadow, a scrupulous roentgenographic technique and careful scrutiny were requisite and only a few workers, who were willing to exercise such care, were rewarded with an increased efficiency in diagnosis.

Thereafter three bases for the diagnosis of cholecystic disease were available: name-

ly, shadows of gallstones, signs of pericholecystic adhesions and the shadow of the gallbladder. Each basis had constituted a step forward; yet after thirty years the goal desired had not been reached. Diagnosis still depended too largely on extraordinary skill, patience and courage and, although a few roentgenologists could point to a fairly high proportion of correct diagnoses, the roentgenologic method for the diagnosis of cholecystic disease was not generally held in high esteem. Nevertheless the medical profession will always be indebted to those men who fought a good fight and kept the faith. Among them, in addition to those already named, were Pfahler, Cole, Case and Manges in America; Knox and Holland in England; Béclère, Mauclaire and Infroit in France; Gottschalk, Haenisch, Witte, Matthias and Fett in Germany and Macleod, the Scot, in China. Besides these there were many others less conspicuous who aided in the common cause.

When the year 1922 was reached on the calendar, examination of the alimentary canal and the urinary tract with opaque media had attained a high degree of excellence and the possibility of extending this method to other hollow viscera was obvious. Rowntree and his associates[7] had shown that kidneys and renal pelves could be depicted roentgenographically after administration of sodium iodide in large doses. Abel and Rowntree[1] long before had determined that chlorinated phenolphthalein is excreted chiefly in the bile; Rous and McMaster[8] had proved that the gallbladder has the faculty of concentrating bile, and chemists had become proficient in forming new compounds by substitution. In retrospect, it is easy now to see that the stage was admirably set for the introduction of cholecystography but the full significance of these events and the logic of associating them together were not then readily apparent and the men of medicine, with one exception, continued merely to wish that a way of making the gallbladder plainly visible with the roentgen rays might be found. That exception was Evarts Ambrose Graham.

"One evening in the winter of 1922," said Graham,[5] "the idea occurred to me that since Abel and Rowntree had demonstrated the fact that the chlorinated phenolphthaleins are excreted almost entirely through the bile, it might be possible, by substituting for the chlorine atoms other atoms which would be opaque to the x-ray, to obtain a shadow of the gallbladder." After several months he obtained some of the free acid of tetraiodophenolphthalein. To render it more soluble it was converted into the sodium salt and in July, 1923, it was injected intravenously into six dogs by Graham's associate, Warren Cole.

In only one dog was a shadow of the gallbladder obtained and that shadow was faint. On inquiry it was learned that by an oversight this dog had been required to fast, while the other five had been fed as instructed. "From the standpoint of the future development of cholecystography," said Graham, "we often feel grateful to that one dog which cast a shadow, probably because he was accidentally given no food. If we had failed to get a shadow in all these animals, we probably would have abandoned the whole idea as a fruitless one. It is curious on how fragile a thread the destiny of some events hangs."

With hope thus revived, Graham continued his experiments and added Copher to the group conducting the investigation. Several animals died after injection of a moderate dose; only later was it learned that the deaths were probably due to impurities in the iodine compound. Meantime recourse was had to the sodium salt of tetrabromphenolphthalein. Excellent shadows of the gallbladder with less toxic effects from the drug were obtained in dogs. Finally a colored woman who presented a characteristic clinical picture of gallstones was given a carefully calculated dose of the bromine salt. To the consternation of the investigators, no shadow of the gallbladder appeared, although at operation many gallstones were found. Quickly, however, it occurred to the little group of workers that the reason for failure of the diseased gallbladder to produce a shadow was that the

organ could not properly concentrate the dye-laden bile. Accordingly the dye was given to a few persons whose gallbladders were supposed to be normal and good shadows were secured.

Thus it became clear that to obtain a distinct shadow the following conditions were necessary: "First, the material must get into the blood stream in sufficient amount. Second, it must be excreted by the liver into the bile in sufficient amount. Third, it must get into the gallbladder. Fourth, the gallbladder must be sufficiently normal to be able to concentrate its contents adequately by the absorption of water. If a single link in this chain of events were defective then either faint visualization or non-visualization would occur." On this rational basis the experiments proceeded with increasing success. The new method was demonstrated before the Congress of Internal Medicine at St. Louis in February, 1924, and a preliminary report by Graham and Cole was published in that month. Cholecystography was on its way.

In 1925 Whitaker and Milliken[10] concluded from experiments on animals that the sodium salt of tetraiodophenolphthalein was preferable to the bromine compound, for the iodine compound could be given in a smaller dose and with less hazard of any toxic effect. Shortly thereafter Menees and Robinson[6] found that either the bromine or the iodine combination could be given to patients orally instead of intravenously.

Roentgenologists everywhere then hastened to apply the test and, although much still remained to be learned, the immediate efficiency of the method was surprising. During its twenty years of existence, progress in cholecystography has been marked by experiments with different mediums, debate as to the relative efficiency of the oral and intravenous methods, investigations into the prevention and treatment of reactions from the drug, studies on the effects of food, drugs and intercurrent disease on the cholecystographic response, trials of various vehicles for oral administration, determination of the optimal time of oral administration in relation to the meal and the appropriate quantity and quality of the meal, application of the various fatty meals to induce emptying of the gallbladder at the proper stage of examination, experiments with administration through the duodenal tube and by enema, advances in roentgenographic technique and in the interpretation of cholecystograms and acceleration of research into the physiology of the gallbladder. Hundreds of informative contributions to the literature have been made. As a result of these and other accretions and adjustments, cholecystography today ranks high among major methods of examination and diagnosis and is justly esteemed to be an almost indispensable adjunct to clinical medicine.

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THE DEVELOPMENT OF MODERN NEUROROENTGENOLOGY

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SINCE anatomical knowledge preceded roentgenography by centuries, the discovery of the latter required only a familiarization with the roentgenographic appearance of well known anatomical structures. This was particularly difficult, however, in the case of such a complicated region as the skull, and later on, when the techniques became available, of the brain. Progress at first was slow, hampered by crude machinery, bulky glass plates, slow and muddy photographic emulsions. Conversely, the development of roentgen apparatus up to the modern anode rotating tube, the application of stereoscopy to roentgenography, the introduction of films, Potter-Bucky diaphragm, intensifying screens and the application of contrast media to the study of the skull and its contents have led to such extensive development in this field of knowledge that one may be justified in applying to it the term *neuroroentgenology* and recognizing its exponents as *neuroroentgenologists*.

However, it would be short sighted, indeed, to credit this progress to mechanical developments alone, without taking into consideration the influence of demand arising from developments in other fields, such as neurological surgery, and above all the human spirit behind these mechanical developments, as well as the spirit that drives men to utilize them for man's needs as quickly as possible.

It is astonishing to find in the medical literature of 1900, 1901 and 1902, only five to seven years after Röntgen's discovery, papers, such, for example, as Benedikt's, devoted exclusively to the application of the roentgen ray to "diseases of the skull and brain." It is true that the eagerness of the early authors to use this great discovery as an aid in the diagnosis of *disease* led them, unfortunately, to fail to inform themselves adequately about the appearance of *normal* structures in the roentgenogram. Their efforts, however, stimulated others, and out of their crude beginnings, a modern science evolved which has become indispensable to neurological and neurosurgical diagnosis.

Refinements in technique and diagnosis began to multiply after World War I in response to demands made upon their roentgenologic colleagues by members of one of the newest specialties, namely, neurosurgery. Thus, familiar names of roentgenologists who are primarily concerned with craniocerebral diagnoses begin to appear in the 1920's and 1930's from centers of neurosurgery: Reynolds, Sosman, Pancoast, Pendergrass, Moore, Chamberlain, Camp, Dyke, Warren, Childes, Kornfeld and many of their pupils, and across the Atlantic, Schüller, Sgalitzer, Lysholm, Lindgren, Twining, and others.

The utilization of knowledge of normal anatomical appearances on the roentgenogram is particularly well illustrated by the recognition of the importance of the location of the pineal shadow. In 1918 Schüller, and in 1925, Naffziger called attention to the fact that the shift of this shadow away from its normal midline position in the anteroposterior or posteroanterior roengenogram of the skull usually indicates the presence of a mass on the side of the brain from which the pineal shadow has been displaced. This was followed by the studies of Vastine and Kinney (1927) and Dyke (1930), all pupils of Sosman, on the charting of the normal position of the shadow of the pineal gland as seen in the lateral roentgenogram of the skull, thus completing this most valuable indicator of the presence as well as lateralization and to some extent also of the localization of many brain tumors.

Other special studies of normal structures such as the optic foramina (Pfeiffer, Camp) and the petrous pyramids (Towne, Stenvers), while applicable to more limited

situations, were, nevertheless of great value in certain groups of cases.

With techniques thus well established and anatomical structures, in spite of wide variations, presenting familiar appearances, the field was open to discoveries of changes characteristic of certain pathological states as seen in the roentgenograms of the skull. In every branch of craniocerebral disease the contribution of roentgenography in diagnosis has become extremely valuable, whether it be in the recognition of congenital anomalies, the results of trauma, the changes associated with tumors, infections or nutritional diseases. It would be impossible, in this brief presentation, to mention all of the contributors to the progress in this field, and unfair to leave any of them out.

In the midst of all this activity, a new technique in roentgenography appeared which has already proved itself of greatest importance in neuroroentgenography and deserves special mention, namely, *planigraphy*. It would be repetitious, for readers of this JOURNAL, for me to describe the principle and technique of this new development. The idea, in fact, was already patented, as long ago as 1922 by Bocage in France, but the credit for its development and application to clinical roentgenography belongs to a young Dutch scientist, Ziedses des Plantes. It is a matter of particular pride to neuroroentgenologists that Ziedses des Plantes is primarily a neuropsychiatrist, and while planigraphy is applicable to other parts of the body, his primary interest was to improve the roentgenologic technique in relation to the skull and its contents.

Ziedses des Plantes is also responsible for a less well known technique which he calls *subtraction*. This consists of making a preliminary roentgenogram of the skull, from which a diapositive is made, with the patient's head so fixed that the exact same position can be repeated later. This is accomplished by having the patient bite into a softened mass of dental wax that is fixed to a rigid frame. Later on, the hardened wax, which fits the patient's mouth exactly, forces the head into the original position. The second roentgenogram is made after gas has been injected into the ventricles. The original diapositive is now superimposed on the negative encephalogram. The positive of the first film blots out the negtive of the second film, leaving in sharp contrast the shadows not common to both films, namely, that of the gas-filled spaces. The same technique may of course be used before and after arteriography.

The principle of introducing a substance into the body which will cast a contrasting shadow on the roentgenogram and thus outline a hollow organ or a potential cavity was developed quite early in the history of roentgenography. As early as 1898 Cannon made use of it by introducing a bismuth mixture into the gastrointestinal tract, and in 1905 Robinsohn and Werndorff were already injecting pure oxygen into joint cavities, sinus tracts, tendon sheaths and tissue planes and obtaining roentgenograms of structures otherwise invisible. In 1913 Luckett published reproductions of ventriculograms occurring spontaneously in a patient who had sustained a fracture of the right frontal bone, as a result of which air was obviously insufflated into the ventricles through the fracture defect. The patient survived, so that air in the ventricles was obviously not fatal. But both the author of this paper and his readers failed to see the significance of this observation. It was not until 1918 that Dandy first introduced air intentionally into the human ventricular system. His first case was that of a child with hydrocephalus in whom he introduced the air directly by puncturing the ventricles through an open fontanelle. Dandy also devised the method of introducing air by means of lumbar puncture, and was the first to try other gases, such as oxygen, in place of air. This discovery was made use of by many workers and the application of it has resulted in a very large number of contributions to our understanding of the anatomy *in vivo* of the brain and of many of the diseases of the nervous system.

Other methods of roentgenologic study of the brain were being developed meanwhile. Thus in 1927 Egas Moniz introduced *cerebral arteriography*. His method consisted of exposing the common carotid ar-

tery surgically, and injecting a contrast medium—at first sodium iodide but later thorium dioxide—and taking successive roentgenograms of the skull to obtain a graphic representation of first the arterial, then the venous pattern of the side of the brain injected. In 1936 Loman and Myerson modified the procedure by devising a method of injecting the radiopaque material into the carotid artery by needle puncture through the intact skin without surgical exposure of the vessel. This method of examination is of particular value in the diagnosis of cerebral aneurysms, angiomas and other vascular tumors. It is also proving valuable in the differential diagnoses of various types of gliomas, many of which like the glioblastoma multiforme, have rather characteristic vascular patterns.

Other methods of studying the brain have also been recommended but have gained fewer adherents than the above methods because of some inherent dangers to the patient. Among these are the use of thorium dioxide in the ventricles of the brain; lipiodol introduced into the ventricles of the brain, and a mixture of gas and lipiodol—favored so much by Balado and his pupils.

Some of our present methods may in the course of time be modified, displaced or completely discarded, but there can be no doubt about at least one thing, and that is that however far the science of neuroroentgenology has progressed to date, its greatest development still lies in the future.

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EARLY HISTORY OF ROENTGENOLOGY OF THE SINUSES

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AS HISTORIAN of the American Roentgen Ray Society I have been asked to contribute something appropriate for the semicentennial of the discovery of the roentgen ray. To recount this discovery and its immediate consequences would be only to tell again what has been adequately covered by Glasser.[6] A survey of injuries resulting from the use of the ray by the pioneers would add little to what is already familiar through the writings of Colwell and Russ,[5] and Percy Brown.[2] I have therefore chosen a topic on which I have had the opportunity to unearth some historical material which is apparently not known to many of our profession, and which I believe deserves recording: the evolution of the early roentgen study of the nasal sinuses. It is fairly common knowledge that American roentgenology of the sinuses began with the late Dr. E. W. Caldwell, and it is known to those who were close to Caldwell that he was stimulated by seeing roentgenograms brought over from Germany. But it took considerable investigation to learn the source of those original roentgenograms. I have been able to trace them to their source and shall give this history a little farther on.

The young roentgenologist of today, or the rhinologist who does his own sinus roentgenography, is apt to have little conception of the laborious steps by which the art was developed to the point where it was offered to him. It was not unknown, before this diagnostic aid was available, to have the following sequence of events: frontal pain, density on transillumination, surgical approach with hammer and chisel, with perforation of the cranial cavity because there was no frontal sinus there; meningitis, and no sulfa drugs or penicillin. It was to forestall this unhappy situation that the newly discovered ray was applied to determine whether or not there was a frontal sinus in these patients.

As early as 1896 Scheier[11] reported having localized a bullet in the cranial cavity, not only in lateral projection but in the frontal, but to show a bullet was one thing and to show the outline of the frontal sinuses in the frontal projection was another. In 1902 Beck[1] mentioned frontal views as a matter of routine, but the reproduction of the lateral projection in the reference cited would not lead to much optimism about the value of the frontal view. In 1902 Winckler[13] reproduced excellent frontal exposures of the dried skull, but confessed his inability to produce worthwhile frontal plates of the living. In 1903 Holzknecht[9] praised Winckler[6] for his contribution to the interpretation of lateral roentgenograms but was quite critical of him for failing to produce frontal views of the living. Holzknecht stated that by using better immobilization than Winckler's lateral roentgenograms showed, and coning down the rays with a lead diaphragm, he produced routinely as good frontal roentgenograms on the living as Winckler did on the dried skull.

In 1902 Philip[10] of San Francisco independently duplicated the procedure of Scheier and of Winckler, to determine that his patient had a frontal sinus, and on a lateral roentgenogram noted to have been made by Mr. Cox of the San Francisco Polyclinic that required eight minutes' exposure at a distance of 20 inches, he demonstrated not only that there was a frontal sinus, but that the tip of his exploring sound was in it.

However, the spark that was to activate the development of sinus roentgenology in America was to come in 1904, when Dr. F. C. Ard, returning from a visit to Killian's clinic in Freiburg, brought to Dr. Cornelius G. Coakley in New York "a

plate showing normal frontal sinuses and one in which suppuration could be readily diagnosed. . . . Dr. Ard stated that the patient lay prone on his face, a photographic plate being placed under the forehead and the tube with a compression apparatus placed on the occiput. The time of exposure was stated to be 3½ minutes."[4]

Dr. Caldwell had died five years before it was my privilege to become the assistant of his former associate, Dr. H. M. Imboden, but his spirit was still very much alive in that office in 1923 and is in 1945, and I have a clear mental picture of Dr. Caldwell, and a first-hand vivid recollection of Dr. Coakley. I can easily enough visualize the incident when Coakley held these plates up before Caldwell and probably said "Caldwell, this is what they're doing in Germany. What's the matter with *you* fellows?"

In the basement of Caldwell's office was a fabulous experimental machine shop presided over by Raphael Paroselli, and my technician is Leo Paroselli, Raphael's son. Leo was born in 1905, a year after this incident, and he does not recall any reminiscence of his father's that bears directly upon it. But there is still in Dr. Imboden's possession a sagittal section of a skull mounted on a board with a protractor, prepared, as was all other experimental apparatus of Caldwell's, by Raphael according to Caldwell's specification. This device was illustrated by Dr. P. M. Hickey[8] in his Caldwell Lecture in 1928, and it shows that the optimum angle of projection was 25 degrees, open cephalad. As a matter of fact, Caldwell used angles of from 23 to 28 degrees, depending largely on the shape of the patient's nose. From Caldwell's pencil sketches, Raphael built a light-weight but strong table, capable of being folded up, with a device supporting the head supine on a canvas sling, the tube in Caldwell's own design of tube stand being under the head, and the plate on a celluloid frame over the face. Throughout the five years I was with Dr. Imboden, this original table was in daily use, and I made many roentgenograms for Dr. Coakley, who would naught of anything but glass plates until their manufacture was discontinued.

I had often wondered as to the source of the roentgenograms that went from Ard to Coakley to Caldwell, but only when I searched the literature for 1907 did I find the answer: Goldmann and Killian[7] speak of having seen excellent roentgenograms of the frontal and maxillary sinuses from Prof. Hägler in Basle. "We at once occupied ourselves with the application and the disagnostic value of this method and in 1904 Goldmann exhibited numerous skiagrams before the Congress of South German Laryngologists in Heidelberg. Some of our roentgenograms were taken by Dr. Ard to Coakley in New York, who through further observations fully confirmed the diagnostic significance of our method for diseases of the accessory sinuses of the nose. The great impetus which the handling of particularly the frontal sinuses by the radical operative method of Killian has had makes it in order for us to review our examinations and, on the basis of a large series of cases, to define our standpoint as to the diagnostic value of the roentgen rays, especially for diseases of the frontal, ethmoid, and maxillary sinuses."

"All the (Freiburg) exposures were made in the Diakonissenhaus by Sister Marie Schmelcher, following the directions of Prof. Goldmann."[7] At the time of this publication (1907) the average exposure for frontal roentgenograms in Freiburg was one and a half to two minutes. Caldwell, who before he became a roentgenologist was an outstanding electrical engineer, was making them at this time in twenty to fifty seconds. To the best of my knowledge, the output of the roentgen equipment did not differ materially in the two countries. Caldwell's shorter exposures, therefore, were at the cost of more electrical energy, driving the tubes to the point of breakdown. The Coolidge tube, be it remembered, came in 1913, and roentgenologists old enough to have worked with the old style gas tubes are now relatively few. The gas tube did

give a beautiful roentgenogram because it was free from the parasitic radiation of the stem; it was the most exasperating inanimate object, temperamentally, that man has ever created. Its conductivity would change abruptly in the middle of the exposure. To run such a piece of apparatus for fifty seconds at a load approximating its capacity ruined any number of these tubes. Caldwell[3] speaks of selecting tubes that would stand such a load out of a large number of run of the mill tubes, and then he states that frequently a tube would be destroyed during the exposure. He stated further that the expense of replacing ruined tubes took all the financial return for his early sinus work. In looking back on sinus roentgenology before 1913, therefore, one can only wonder at the excellence of those early roentgenograms made on glass plates. In fact, one can wonder that they had sinus roentgenograms at all.

"The diagnostic value of the X-rays especially for diseases of the frontal, ethmoid, and maxillary sinuses." Thus Goldmann and Killian in 1907. Eloquence can reside in omission as well as in expression. Caldwell's estimate of the value of roentgenology with respect to the sphenoid sinuses was similar to that of Goldmann and Killian. Caldwell studied projections of the sphenoids anteriorly and posteriorly, up and down and sideways, and he refused to give any opinion on the sphenoid sinuses, because he said he was not being paid to guess. Just as some progress has been made in the treatment of arthritis since the time that Osler advised young physicians to run out the back door and jump over the fence when a patient came in with arthritis, because he would earn more ultimate gratitude from the patient by so doing, some progress has been made in the intervening thirty-eight years on the roentgen diagnosis of the sphenoid sinuses. But an account of it has no place in a consideration of the early history of roentgenology of the sinuses.

The transition between the early period and the modern period in this branch of roentgenology, it seems to me, is just about when Waters[12] contributed the angle which bears his name. We are prone to think of the Waters position as having its principal value in the improved visualization of the antra, the petrous shadows being thrown below the antral shadows, but Waters called attention to its value also in showing the anterior and the posterior ethmoid cells. Those who are accustomed to using both the Waters and the Caldwell projection would be very loath to rely on either one without the other.

The original posteroanterior projection will probably long be known in this country as Caldwell's angle, and he did work out the angle for it independently; but approximately the same angle he established had been used a little before him by Goldmann in Freiburg, who acknowledged the priority of Hägler in Basle. It was Basle where the Basle Nomina Anatomica originated, dedicated to an attempt to supplant proper names in anatomy. However, as long as roentgen rays come out of Coolidge tubes, we shall probably continue to pay tribute to Caldwell and to Waters as among the earliest and still the most promiment contributors to roentgenology of the sinuses in the United States.

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HISTORY OF THE ROENTGEN RAY IN THE STUDY OF THE HEART*

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VERY soon after the discovery of the roentgen ray, the heart and great vessels were submitted to examination by its use. There was no need for complicated procedures; the conditions of contrast were optimal, and there was no inconvenience to the patient. To do justice to even the pioneer workers in an article of this scope is obviously impossible when one considers that the list of books and pamphlets on the roentgen ray published during 1896—the year after its discovery—as given in Glasser's book,[3] totals 1,044 items.

The first period of investigation extends to perhaps the year 1900; many instructive cases were published that dealt chiefly with single observations. Details were searched for, the principles of projections were realized, and even as early as 1896 mention is made of calcifications in the aorta by Levy,[11] and in the peripheral vessels by Hoppe-Seyler.[7]

By 1900–1901 exact methods were developed and a systematic evaluation of the physiological foundations had taken place. The introduction of the orthodiagraphic method by Moritz[12] and Béclère,[1] the analysis of the normal and pathological aorta by Holzknecht,[5,6] and the correlation of roentgenologic and clinical findings by Williams[16] represent the great advances made at that time. It is instructive to read in Williams' book his pointing out the errors in percussion, his reports on follow-up studies on effective treatment, and his stressing of the diagnostic and prognostic appearance of the lesser circulation. One of his important observations refers to what we would now call the beriberi heart.

In 1905 Köhler[9] introduced the teleroentgenographic method, which soon became a common possession.

Subsequently a systematic evaluation of the pathologic conditions of the heart and great vessels developed, with emphasis being placed on certain constitutional features, and there was an increasing correlation with anatomical and physiological data. To refer to the many small mosaics that have ultimately led to the integrated science of today would require the writing of a treatise in this field. Therefore only a few lines of development are pointed out.

Although many excellent observations were made as to the movement of the cardiovascular silhouette, objective registration did not arrive until 1911 with kymography, and among the contributors to this technique were Sabat,[15] and Goett and Rosenthal.[4]

A better understanding of the inner topography of the cardiovascular silhouette has been obtained in a twofold way: first, by correlating in a systematic fashion the roentgenologic appearance with anatomic sections (Koch and Wieck[8]); second, by opacification of the heart and great vessels in the cadaver—of the right-sided cavities and the lesser circulation, and of the left-sided cavities and aorta, respectively—and the appropriate use of various views (Laubry, Cottenot, Routier and Heim de Balsac[10]).

In the living, angiocardiography was introduced by Forssmann,[2] and valuable findings were obtained by the method developed by Robb and Steinberg.[14] The plastic reconstruction of the heart by Palmieri[13] was also an important contribution.

Although this brief résumé seems to stress the technical aspects of progress in cardiology, it must not be forgotten that the advance attained and the refined diagnostic possibilities afforded by the methods in use today have come from a healthy interplay between men who were primarily

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interested in technical and morphological problems and other men who could offer their critical, anatomical, physiological and clinical experience. Almost all of the contributions—as one studies them in retrospect—have been a mixture of truth and error, but the truth has been retained through an interesting and peculiar process of sifting. Sooner or later the names of the individual contributors to a science fade as the science grows, and this is as it should be, for science is a structure in the process of building. When the temple is completed, we admire its beauty but think not of the laborers who laid the stones.

The celebration of anniversaries is a wholesome thing, for it freshens our sense of indebtedness to our forerunners but, by the law of opposites, it leads to anticipation as well as to retrospect—to a surmise of the one hundredth anniversary of Röntgen's discovery and the hope that the cardiologists of that day will have completed their study of cardiac pathology and will be celebrating victories in its prevention.

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THE HISTORY OF THE USE OF THE ROENTGEN RAY IN WARFARE

CALDWELL-CARMAN LECTURE, 1944*

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WITH the passing of years the personality of a man recedes into the background and his ultimate place in history is determined by the contributions which he has made to science and society. While Carman did not create fluoroscopy he took this as a method of examination and perfected it in the study of the gastrointestinal tract and transmitted it to us as a fine heritage. And no matter how we in these later years change slightly here and there this method of study, primarily it is Carman's in a new phase or variation.

Caldwell was one of those rare individuals who combined a scientific and a mechanical attitude of mind toward the solution of many of the difficult problems in the early days of roentgen diagnosis and therapy. His position in the roentgenological world stands on a sure footing. Not only did he contribute mightily to the solution of the diagnostic problems which confronted roentgenologists in the early days but his knowledge of engineering enabled him to help solve many of the mechanical problems of those working in roentgenology, and many of the gadgets which we use today in the examination of patients had their primary inception in the mind of Eugene Caldwell. These two societies honor themselves in honoring the memory of Eugene Caldwell and Russell Carman.

In normal times one might choose for the Caldwell-Carman Lecture a subject of more scientific interest but in these times when all our thoughts and actions are geared to total war, I thought it would be interesting to sketch the history of the uses of the roentgen ray in warfare.

ETHIOPIAN CAMPAIGN

The science of roentgenology made its appearance late on the horizon of medicine and surgery. The possibility of its use in warfare was quickly seized upon, and its first practical employment in war surgery was in the examination of some of the soldiers returning from Italy's ill fated Ethiopian campaign where the Italian Army suffered a crushing defeat by the Ethiopians at Adowa on March 1, 1896. The examinations were made by Lieutenant Colonel Alvaro[2] at the Military Hospital at Naples in May, 1896. The roentgen-ray apparatus which he used was not the primitive apparatus of Röntgen since subsequent discoveries permitted modifications and amplifications. It consisted of a series of accumulators connected with an interruptor and commutator; a Ruhmkorff coil and a Crookes tube, not oblong in form but pear shaped, through which several metallic wires were run, one of which was fastened to a small concave disk serving as cathode.

The procedure of practical application of the roentgen rays was described as follows: One takes a prepared photographic plate, places it in several layers of black paper, then puts it in a cardboard or wooden cassette, or on a small taboret in such a way that the impressed gelatinous surface is toward and underneath the part of the body of which the shadow is to be taken, it being fixed in this position with gauze. Above is placed the Crookes tube at a distance of 20 to 30 cm., the current being generated by the Ruhmkorff coil.

* Delivered at the Joint Meeting of the American Roentgen Ray Society and the Radiological Society of North America, Chicago, Ill., Sept. 24–29, 1944.

After twenty minutes, or a good half hour or longer, according to the potential of the current, and the nature, thickness and density of the part, one obtains a negative with a relative white shadow on a black base.

The two cases which were the basis of Alvaro's report were wounded soldiers returned from the battle front at Ethiopia. Fortunately, these two soldiers were wounded in the forearms which rendered their examination fairly easy, considering the feebleness of the equipment. The projectiles were removed following the roentgen studies and the wounds promptly healed. Attempts had previously been made to remove these bullets but they were unsuccessful until the roentgen ray was used in their exact localization.

Attention was called by Lieutenant Colonel Alvaro to the valuable help which the roentgen rays could give to the surgeon, especially when there was a question of determining the position of a foreign body, or of diagnosing a bone disease, or judging the form of a fracture, or studying the deformity of the skeleton and the formation of internal concretions. He was possessed apparently of a prophetic vision for in these faroff days he sensed the possibilities of the roentgen ray not only in military but also in civilian hospital use and predicted for it a great future.

From these early beginnings in the use of the roentgen ray in warfare we have travelled a long way and more recently Naples has seen other soldiers and other roentgen-ray equipment land at her ports.

GRECO-TURKISH WAR—1897

The Mediterranean basin in those years, as in these later years, was the theater of wars and quickly upon the heels of the Ethiopian War came the Greco-Turkish War of 1897. As in all wars in which the Balkan states were involved, the great powers of Europe took sides and in the Greco-Turkish War the German sympathies and their support were with the Turks, while Russia, England and France lent their support to the Greeks.

It was during this war that the first opportunity for the study of the usefulness of the roentgen rays in hospitals located close to the front was provided. The Central Committee of the German Red Cross sent a hospital unit which was located in Constantinople. At the disposal of this unit was placed a roentgen apparatus. Dr. Küttner who accompanied this hospital reported his experiences in the use of the roentgen ray.[17] He found that it was of great help in establishing the position of the embedded bullets, immensely facilitating their removal, and it was particularly helpful in cases of osteomyelitis or draining wounds, in determining the extent of the fractures and the presence or absence of the bullets or fragments of lead or clothing. The roentgen procedure was found of great value in the estimation of injuries to the nervous system. Especially where there was a severe paralysis they were able with the roentgen ray to determine whether the paralysis was a result of compression of the spinal cord by dislocated bone fragments or by bullet injuries, thereby determining the advisability of an operation. Even in paralysis of the peripheral nerves it was possible to differentiate between injury due to pressure from bone fragments and injuries due directly to a penetrating bullet.

Küttner discussed the importance of the roentgen ray and also the feasibility of its use at advanced line hospitals. From his experience with the bulky type of machine which they used he concluded that the roentgen ray could only be employed in the reserve or base hospitals and not in a field or evacuation hospital.

The British Red Cross also sent hospital units for the aid of the sick and wounded of the Greek army. Two hospitals were established, one in a villa at Phalerum and the other at Chalcis.[1] Both of these cities were frightfully overcrowded with thou-

sands of refugees, which complicated the proper handling of the sick and wounded. The British units were supplied with a powerful coil and all the other essentials for roentgen-ray work and, since it was the only apparatus of its kind in Greece, these hospitals received cases from other surgeons to supplement their own and were in a position to gain a large experience in bullet wound cases. The only difficulty that was experienced with the roentgen-ray apparatus was with the batteries, the extreme heat melting the pitch of the partitions between the cells. The coil which the British surgeons used gave a nominal 10 inch spark. They used only three Crookes tubes throughout the campaign but from their experience they thought it was advisable to have a good reserve of tubes. The equipment also included a fluoroscopic screen which proved the means of saving much time and which is stated was probably even more necessary in war than in work elsewhere.

Some of the difficulties in the use of the roentgen rays in war as they presented themselves to the British unit were the great weight of the coil and secondary battery, the absolute necessity of having a source of electric supply near at hand to recharge the batteries, the fragility of the Crookes tubes and glass negatives, the danger of carrying strong sulphuric acid, the difficulty of sparing the space and of making an efficient dark room with good water supply, besides the general delicacy and liability to derangement of the whole apparatus. A more amusing source of difficulty in this particular campaign was the superstition of the natives. They looked on the whole affair as the work of the Devil which made it difficult to take a skiagram when the subject was constantly crossing himself unless strictly watched.

The problem of the source of electricity was solved by the fact that the hospital was at Phalerum and they were able to obtain an electric supply from *H.M.S. Rodney*. The hospital at Phalerum was also close enought to Athens to enable the Greek surgeons to send up such cases as needed roentgen studies.

During the Greco-Turkish war the Mauser rifles and the Martini-Henry rifles were used and the bullets from these then modern implements of war were much less frequently found in the body due to the high velocity of the bullet. The hole of entrance of the bullet was extremely small. Suppuration of the wounds was generally due to pieces of clothing carried into the tissues. Wounds of the lung by these modern bullets ran a comparatively favorable course. Lead bullets were used in this campaign and characteristically they left particles of lead along their paths.

It was the impression of the British surgeons and roentgenographers that the roentgen apparatus would prove of no use on the field, first because of the size and bulk of the machine, and second, they thought that its use at the front might be an incentive to surgeons to premature operations in bad surroundings.

THE TIRAH CAMPAIGN—1896

The sympathy of the English for the Greek Nation during the Greco-Turkish War caused deep annoyance and indignation among the Turks. This feeling was propagated through the Mohammedan countries. So, at far away Peshawar in Northern India, near the Khyber Pass, agents from Constantinople made their appearance, stirring unrest among the tribes and members of the Mohammedan faith in that part of the world.[21]

Khyber Pass is one of the most important mountain passes in the world[14] (Fig. 1). It leads from Afghanistan into India and is a narrow defile winding between cliffs 600 to 1,000 feet high, stretching up to more lofty mountains beyond (Fig. 2). Perhaps no other pass in the world has possessed so much strategic importance or retains so many historic associations as this gateway to the plains of India. The great invasions of India which have oc-

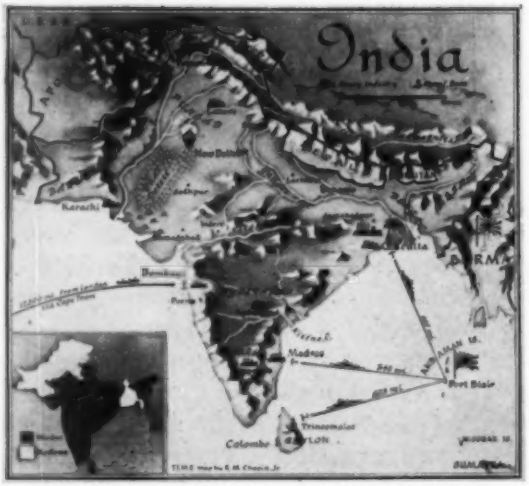

FIG. 1. Reproduced, by permission, from *Time*, September 14, 1942.

curred in this area have gone through it. Since this Pass lay in such a strategic position and was so important to the British in India, it became necessary for the British to negotiate with the local tribes, the Afridi and Orakzai, for its free use to safeguard the passage into India. After many attempts at appeasement of these warlike tribes, the British succeeded in obtaining at least a temporary cessation of hostilities prior to 1897. The scheme which was adopted was an arrangement with the Afridis by which they agreed to keep open the Khyber Pass on behalf of the British Government. Several forts were built and to garrison them a corps of riflemen was formed, entirely composed of tribesmen living in the neighborhood of the Pass. For a while these natives gave the regular troops of the Indian Army great assistance.[20] However, following the agitation among the Mohammedans, the Afridis and the Orakzais decided to revolt against the British and they seized the forts in the Khyber Pass, closing it to travellers and to military transports. The British-Indian Government, realizing the importance of the Khyber Pass itself and the menace of the revolt among the natives, sent an expedition to quell the uprising. This campaign is known as the Tirah Campaign.

The Tirah country, lying high in the plateaus of the Skofed mountains (Fig. 3) was at that time unknown to the outside world;[15] it served as the summer resting place of the native Afridis and Orakzais (Fig. 4 and 5). No white man, certainly no troops other than native troops, had ever invaded the region until the armies under the leadership of General Sir William Lockhart began their expedition into the territory in October, 1897.[16]

Twenty-three field hospitals altogether were mobilized for service in the Tirah Campaign. The wild, entirely roadless country in which the military operations were conducted increased the difficulties with which the medical department had to contend in making arrangements for the care, treatment and transport of the wounded and sick. Many of the wounded had to be carried on stretchers and to be escorted all the way throughout the hostile

FIG. 2. The Dwatoi Defile. Reproduced from Warburton.[21]

territory, experiences not unlike those in the present campaign in India and Burma.

One notable feature of the medical arrangements was the use of roentgen rays for the first time on the field of battle. They were found of the greatest value in

Fig. 3. Reproduced from Shadwell.[20]

locating bullets and splinters of lead. The apparatus was brought out (entirely at his own expense) and operated by Surgeon Major W. C. Beevor,[4] to whom all the credit of the innovation is due. From his experience in the Tirah Campaign, Major Beevor called attention to the importance of the organization and the type of apparatus and materials to be used in warfare. The first desideratum in the construction of all apparatus for military work, he concluded, is that they be "get-at-able," thus enabling one to renovate the inevitable defects of wear and tear. Every portion of the apparatus should be easy of access; the coils, condensers, connections, etc., should all be packed in cases that can be opened and inspected in a moment's notice without special instruments. In addition, the operator of the roentgen apparatus should be independent of help.

Beevor was supplied with only three tubes. They were used in more than two hundred cases in Tirah; they went all through the rough transport country and they landed back at Rawal Pindi in as good

Fig. 4. Afridi villages below Ali Masjid. Reproduced from Warburton.[21]

working order as when they were taken out.

The question of transport for the equipment offered some difficulties, but even in the wildest part of the country they were able to transport it and to use it effectively in the examination of the injured. Its greatest value, of course, was in the localization of bullets and other foreign bodies and also in determining the extent of the injury to the bone structures. From his experience, Major Beevor concluded that every civilized nation is duty bound to supply its wounded in war with roentgen apparatus, not only at base hospitals but in the field.

After trying every kind of transport in India—mules, camels, wheeled vehicles, etc.—Beevor found that the safest and most satisfactory was human transport. In Tirah he employed Dhoolie bearers and they carried the whole apparatus from Bagh Camp in Tirah, down the defile to Dwatoi, and down the Bara Valley to Peshawar without injury. Parts of this march were beset with difficulties seldom experienced in any kind of warfare. They encountered rocks, icy cold water, rapid torrents, frost and snow which did not interfere in any way with the apparatus.

The greatest problem involved in operating the apparatus was the generation of electricity. The only means Beevor had at Tirah was a heavy and cumbersome primary battery worked by a mixture of bichromate of potash and sulphuric acid. The latter was too dangerous for military transport unless accompanied by someone especially to look after it. Therefore he condemned this form of battery for field

Fig. 5. Tirah. The Orakzai Jirgah. Reproduced from Warburton.[21]

work and recommended the employment of a hand dynamo and portable accumulator. This combination had many advantages—it could stand rough transport and in case one got out of order the other could be substituted.

As in the former campaigns, the fluorescent screen seemed the most important part of the apparatus. The screen surface was protected with a layer of celanite and the whole was enclosed in an aluminum case.

In roentgenographic work the glass plates were found to be most satisfactory, in spite of danger of breakage in transport. Beevor had three dozen at the beginning of the Tirah Campaign and through all the adverse conditions they proved satisfactory, giving at the end of four months' rough travel as good results as at the beginning.

Fig. 6. Sketch map. Distances and principal points in the Nile Valley. Reproduced from Churchill.[10]

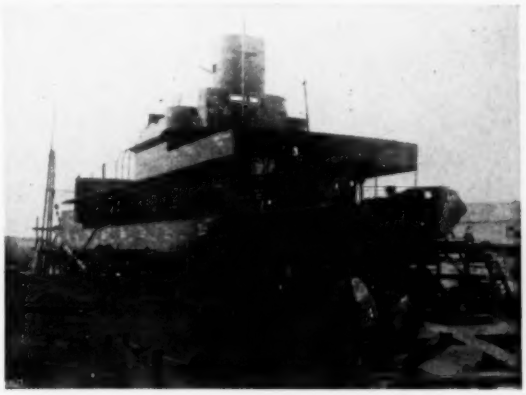

Fig. 7. The new stern-wheel gunboat in the shipyard at Wyvenhoe. Reproduced from Churchill.[10]

War of the Soudan—1896–1898 (The River War)

The Tirah Campaign was in progress at the time when the financial state of the Egyptian government, under the supervision of the British and their collaborators, had reached such a point that attention could be given to the recurrent outbreaks of hostility among the tribes in the Soudan (Fig. 6). This decision was made the easier by the fact that the assassination of an Englishman, General Gordon, several years before at Kartoun by the natives of the Soudan had rankled in the hearts of the British and had been a source of considerable controversy in the British government. It was decided to send an expeditionary force up the Nile to subdue and conquer the natives in the Soudan, and Lord Kitchener was chosen as the head of the expedition. His organization consisted not only of British units but of well trained Egyptian military units and a certain number of natives. The journey up the Nile was made in slow stages accompanied by vessels suitable for transport on the Nile. In this heterogeneous army there were two men whose subsequent activities were to influence the world—Winston

Fig. 8. The Nile at Abadieh. Eight miles north of Berber, where advanced base Surgical Hospital was situated, and also headquarters of x-ray work. Reproduced from Battersby.[3]

Churchill,[10] an officer in the cavalry, and a junior naval lieutenant in command of one of the gunboats (Fig. 7), Lieutenant Beatty, afterwards Admiral Beatty of Jutland fame.

Numerous engagements were fought in the journey up the Nile and in each of these the natives were defeated. They continued to retreat up the Nile to their main headquarters at Omdurman. It was at Omdurman that the Dervishes received their crushing defeat at the hands of Lord Kitchener and his army, which has been described as "the most signal triumph ever gained by the arms of science over barbarians. Within the space of five hours the strongest and best-armed savage army yet arrayed against a modern European power had been destroyed and dispersed, with hardly any difficulty, comparatively small risk, and insignificant loss to the victors." It is also of interest to note that among these arms of science was a roentgen-ray apparatus.

The man in charge of the apparatus was Major Battersby.[3] Before he left Cairo he took the precaution of having very thick felt covers made to surround the outer boxes containing the coils and storage batteries, and, by keeping them constantly wet, the internal temperature of the coils was considerably reduced, as the evaporation in the Soudan was very rapid, the temperature varying from 100° to 122° F. in the shade.

Between Wady Halfa and Abadieh, the site of the base hospital (Fig. 8), all the apparatus had to travel for two days and a night in an open truck, exposed during the daytime to the fierce heat of a blazing sun. By keeping the felt wet every two hours, they reached their journey's end without mishap to the apparatus (Fig. 9).

In the Soudan some 60 observations were made by the screen and plates. In bullet wounds of the upper or lower extremities anteroposterior and lateral views (Fig. 10 and 11) gave sufficiently comprehensive information as to the position of the bullet but in the deeper structures the best results were obtained by a modification of Mackenzie-Davidson's localizing apparatus (Fig. 12).

As in the Tirah Campaign the roentgen-ray outfit which accompanied the army in the River War had to be portable and suitable for mule, camel or human transport, as often during the journey up the Nile, narrow defiles and mountainous passes had to be traversed. One of the most serious difficulties, ever present in all campaigns, was the generating of the primary electrical current for charging the storage batteries or working the coil direct. In the Soudan Campaign a small dynamo driven by means of a tandem bicycle (Fig. 13) answered this problem admirably and was readily transported by rail and

Fig. 9. Major Battersby and his orderly taking a radiograph. Reproduced from Battersby.[3]

Fig. 10

Fig. 11

Figs. 10 and 11. Bullet in knee (front view, Fig. 10); bullet in knee (side view, Fig. 11). Reproduced from Battersby.[3]

river to its destination at the hospital at Abadieh.

The roentgen-ray outfit consisted of two 10 inch and one 6 inch coil and these, with the other necessary electrical instruments, were enclosed in a strong oak box. While the apparatus was most complete and satisfactory, it was for the requirements of field service too heavy for camel or mule transport. Consequently a special arrangement of ropes was made, by which means, and by the aid of a long pole, it could be carried on the shoulders of four men. The apparatus further consisted of a storage battery with separate cells which proved more useful than having them fixed in a wooden case, because if a cell became injured or a plate buckled, it could be taken out of the circuit and a spare one substituted.

Battersby also brought with him four 10 inch ordinary bianodic focus tubes. These were personally tested before leaving. Two of these tubes did most excellent and extensive work, one being better for screen work and the other for roentgenography.

The fluorescent screen was found most useful at night, but unsatisfactory during

Fig. 12. Localizing apparatus. Reproduced from Battersby.[3]

the day owing to the intense sunlight which, do what they would, seemed to penetrate the hood, no darkroom being available. The surface of the screen was protected by a layer of celluloid, which in a warm and dusty climate was a matter of no mean importance.

The photographic materials and developers in these early days were rather crude and much had to be learned in this regard. Glass plates alone gave satisfactory results.

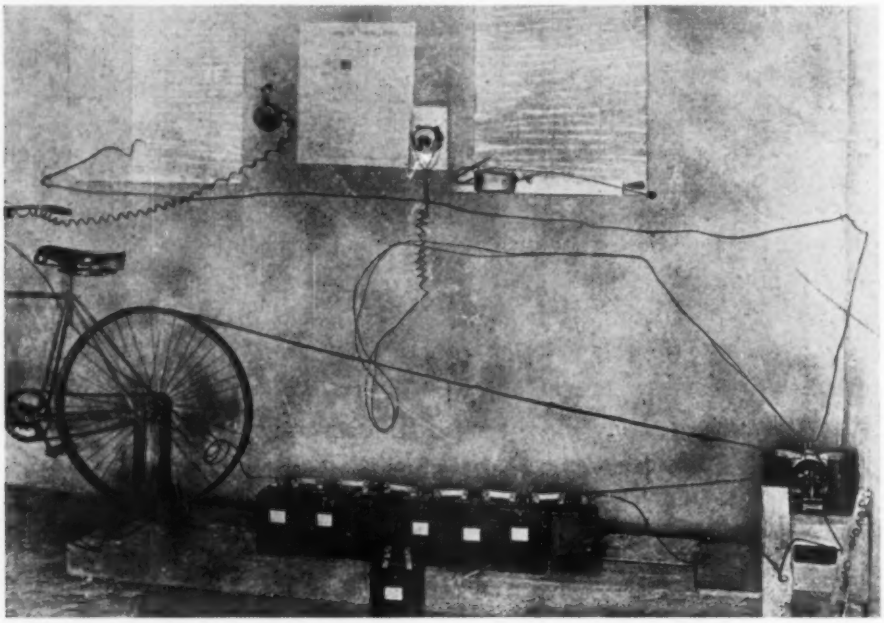

FIG. 13. Method by which electricity was generated for charging storage batteries. Reproduced from Battersby.[3]

The total number of casualties in the British Army at the Battle of Omdurman was 175. Of these, 121 were conveyed to the surgical hospital at Abadieh. Of this number there were 21 cases in which the bullet could not be found or its absence proved by ordinary methods. In 20 of these 21 cases an accurate diagnosis was arrived at with the help of the roentgen ray.

THE GREAT BOER WAR—1899

These little wars in which the roentgen ray became a camp follower were followed by the Great Boer War in 1899. If one looks at the map of South Africa, he will see there in the very center of the British possessions a great stretch of the two republics which comprise the lands of the Boer nation (Fig. 14). The Boers are the descendants of those hardy Dutchmen who for fifty years defended themselves against Spain which was then the greatest power in the world. Intermingling with this Dutch strain were the French Huguenots who left their country at the time of the revocation of the Edict of Nantes. These virile formidable people and their progeny had for seven generations trained themselves in a constant warfare against savage men and ferocious beasts under circumstances which no weakling could survive. They became a law into themselves, recognizing no government except that which they themselves had established. These Dutch emigrants made their first landings at the Cape of Good Hope in 1652 and for one hundred years the colony spread gradually over the huge expanse of veldt which lay to the north. They remained happy and contented in their new

country until the world was suddenly startled by the announcement of the enormous gold and diamond mines in that part of South Africa. The Boers then saw their lands being occupied by outsiders and they set about to prevent this by the issuing of certain laws governing citizenship and it was the imposition of these laws soon found themselves pitted against a formidable foe and had made inadequate preparations for it. The War of the Soudan having been completed, the medical units, together with the roentgen-ray equipment which had been used in that war, were ordered to South Africa.

The Siege of Ladysmith in the Boer War

Fig. 14. Reproduced from Doyle.[11]

and certain other small episodes which ultimately brought about the South African or the Great Boer War with England.

Conan Doyle,[11] in commenting on this war says: "Our military history has largely consisted in our conflicts with France, but Napoleon and all his veterans have never treated us so roughly as these hard-bitten farmers with their ancient theology and their inconveniently modern rifles."

The British, contrary to their thought, furnished the first occasion in which roentgenography was attempted under such conditions. It was here also that actual work was first done under shell fire for any long period.

Lieutenant Bruce[6] of the British Army who was stationed in Cairo, received his orders to proceed to Natal and to take a complete roentgen-ray unit. This unit was available but to arrange for a supply of electricity was not so easy. From his

experience up the Nile he knew that it would be useless to take the specially fitted-up bicycle which had been used as a motor for a dynamo. Bruce confessed that he had no faith in manual aid for driving a dynamo and he could speak from experience because he was in the Nile campaign and with the temperature in the hut over 100 degrees this style of charging batteries left an impression on him that his relationship with a dynamo was extremely small. Consequently he had the batteries charged before he left Cairo. In addition, he took along the usual roentgen apparatus and a dynamo, trusting that some means might become available to drive it.

The destination of Lieutenant Bruce was Pietermaritzburg, which he reached without any mishap. He later had orders to proceed to Ladysmith, which he did on October 16, taking all apparatus with him. A portion of the Town Hall was used for the x-ray department. The first series of cases were very soon furnished from the battle of Elandslaagte. The number of cases from this battle which required examination was not very large. Few patients had to be examined for bullets, the majority of the wounded having bone injuries. This absence of imbedded bullets may be accounted for by the fact that the firing was at short range, and those bullets which did not pass through the parts caused severe injuries to the bones when these obstructed their course. All the bullets were successfully localized and subsequently extracted. Fortunately, in that work none of the bullets lodged in the pelvic region, as the Mauser bullet, being so small, proved very awkward to find in deep tissues.

During the period from October 30 to November 3, shells were continually dropping in the neighborhood of the hospital. Nevertheless, the work in the roentgen-ray room was carried on as usual. Great caution had to be used in roentgenographing the patients when shells were heard in the immediate vicinity, as they were sure to start, thinking the building would be hit. Exposures under these conditions had to be of the shortest (probably only ten or fifteen minutes instead of the usual twenty or thirty), necessitating long developments. They eventually arranged for a lookout to announce the firing of the gun, which did much to facilitate their work.

As it was apparent that considerably more work would have to be done, there became the problem of charging the batteries. Bruce knew that close to the Town Hall was situated a flour mill and he asked for permission to have the dynamo driven from the mill shafting. This worked remarkably well and charged the batteries most efficiently.

Among the wounded, some interesting cases were roentgenographed, showing the behavior of the expanding bullet used by the Boers. They showed the lead scattered about the injuries in all directions, the mantle remaining nearly intact. The number of cases actually recorded was 200, of which nearly one-half was roentgenographed. In addition, a vast number of cases under treatment were examined by the surgeons with the fluoroscopic screen. As in the Nile campaign, work with the screen was best done in the evening unless the roentgen department was so situated as to permit of darkening the room in the daytime.

In regard to the general results by the roentgen apparatus, all were unanimous in saying that it was of the greatest assistance, not only in locating bullets but also as an aid in the treatment of fractures generally.

The great demand for the increased use of the roentgen ray in army campaigns was best emphasized in this war in that each of the general hospitals had a complete outfit and many of the smaller ones had the necessary apparatus.

It is of historical interest to note that at the time of the Siege of Ladysmith, Winston Churchill[9] had landed at Durban and had made his way to Estcourt where he became a member of that group which attempted by means of an armoured train to pass through the enemy's lines. The

story of his capture by the Boers, his imprisonment and his subsequent escape is too well known for comment.

THE SPANISH-AMERICAN WAR—1898

In the Spanish-American War roentgen-ray apparatus was used to a limited extent due to the type of warfare and to the fact that the activities of the Medical Corps were consumed in caring for those ill with typhoid fever. However, the more important of the general hospitals and three hospital ships, namely the *Relief*, the *Missouri* and the *Bay State*, were supplied with roentgen-ray apparatus. The type of apparatus used in the hospitals was essentially that used in the previous wars, that is, coil apparatus and storage batteries, the more recently constructed static apparatus, this last being so heavy that its use was confined to fixed hospitals and hospital ships.[5]

WORLD WAR I

With the close of the Boer War and the signing of the treaty of peace following the Spanish-American War, there was a period in which the whole world seemed to be free of wars. During this time great strides were made in the manufacture of technical equipment of all kinds. An unprecedented era of invention and research developed, with advances in all fields. The progress of the science of roentgenology did not lag behind. The generating source was gradually emerging from the chrysalis stage of coil and batteries, and radical changes were made in tube designs.

Then came World War I, a war the magnitude of which, in comparison to the former small wars is most vividly expressed by the following now famous description by Winston Churchill:[8]

> The wars which had preceded World War I were the kind of warfare full of fascinating thrills. Nobody expected to be killed. Here and there in every regiment or battalion, half a dozen, a score, at the worst thirty or forty, would pay the forfeit; but to the great mass of those who took part in the little wars of Britain in those light-hearted days, this was only a sporting element in a splendid game. Most of us were fated to see a war where the hazards were reversed, where death was the general expectation and severe wounds were counted as lucky escapes, where whole brigades were shorn away under the steel flail of artillery and machine-guns, where the survivors of one tornado knew that they would certainly be consumed in the next or the next after that.

This was really war with all its grim tragedy.

It was not a coincidence that when the demand on medical skill at once became so enormous, the immeasurable importance of the roentgenologist should have sprung to the front. By this time the invention of the Coolidge tube had done away forever with the capriciousness of the gas tube, and in 1916 the introduction of the Potter-Bucky diaphragm had freed the roentgen images of their fogginess and indistinctness.[19] Fortunately, as a result of these two great discoveries, the American Expeditionary Force of World War I was supplied with the finest roentgen-ray equipment that the world had known up to that time.

Welch,[12] returning from the war front, in an address before the Johns Hopkins Hospital Medical Society on November 6, 1917, said that on and around the foreign battle fields there was an opportunity of using to the full all the recent medical discoveries, among them advances and improvements in the way of inoculations against disease, in sanitary matters, pure water and incineration, and in the use of the roentgen rays which he declared to be of incalculable advantage in conditions of war.

World War I had been in progress three years before the entrance of this country into the conflict and during these years the European countries continued to use the induction coil equipment, especially for their mobile war units. They also employed the gasoline engine driven dynamos or generators for their current supply, making use of either the engine of the truck that

carried the apparatus, or a separate engine. They continued with this type of exciting apparatus with the gas tube through World War I.

It may be of interest to note at this juncture that the first Coolidge tube which the French saw in operation was in the American Military Hospital No. 1 in 1917. Dr. Bèclére and his group of students made a special trip to the hospital, where I was stationed, one Sunday morning to view the tube in operation.

Previous to our entry into the war some of the more thoughtful members of these two societies, realizing the urgency and need not only for equipment but also for trained roentgenologists, since there was an inadequate supply of the latter, set about to remedy this defect. It is true that both the Army and the Navy had roentgen-ray equipment in their hospitals, and for some time before World War I all the Army medical officers were given limited practical courses of instruction with the roentgen apparatus then available. Upon the entry of this country into the war, with the sudden and rapid expansion of both the Army and the Navy, it was necessary to take these men who had had training in roentgenology and utilize them in other medical activities of the Army and Navy. Surgeon-General Gorgas recalled to active service Colonel Arthur C. Christie and acting on Colonel Christie's advice created a division of roentgenology of the Army Medical Corps. General Gorgas placed Colonel Christie in charge of this division and he in collaboration with a number of roentgenologists quickly organized medical centers in all parts of the country for the training of roentgenologists and technical assistants and repairmen. Many of the latter were promptly supplied by the manufacturers. At the same time he called into consultation the manufacturers, seeking to improve especially the portable type of apparatus which was necessary for the advance hospitals, and in collaboration with Dr. Coolidge there was soon evolved a small gasoline engine for the generation of electricity, this engine being reduced to the absolute minimum as regards the parts so that it would require the least amount of technical care. This, coupled with the transformer and the Coolidge tube, represented an enormous advance in the portable equipment; not only could it be used at the front line hospitals, but also as an auxiliary unit in the fixed hospitals.[7]

During the progress of the war there was introduced as a result of Major Shearer's efforts a bedside unit using the radiator type of Coolidge tube and this unit was extensively employed in the large stationary hospitals both at home and abroad.[13] There was also constructed a standard United States Army roentgen-ray table which is well known to all roentgenologists. It is of interest to note that at the time of the Armistice almost a thousand sets of roentgen-ray apparatus of various kinds had been sent abroad. The schools established for the instruction of roentgenologists began classes in July, 1917, very shortly after our entrance into the war, and by the end of December, 1917, over two hundred men had been trained to serve as roentgenologists. These men quickly supplemented the inadequate number at the beginning of hostilities. Not only was the roentgen ray used in the localization and removal of projectiles, shell fragments and bullets and other foreign bodies, but also for the diagnosis and control of fractures and dislocations. Furthermore, for the first time in warfare the roentgen ray played an important rôle in the early diagnosis of gas gangrene, one of the most devastating and crippling infections encountered on the battle fields of France.

The Committee for the Organization of Schools and the Teaching of Roentgenology sent an official report to Surgeon General Gorgas in which the suggestion was made that in addition to a careful clinical examination of the chest a roentgenological examination of every recruit for the Army or Navy should be made in order to determine his fitness for the service. Unfortunately, this recommenda-

tion was not accepted. Twenty-five years later, in World War II, we saw the fruition of this official recommendation.

We all owe a great debt of gratitude to those far sighted individuals who, recognizing the needs of the Army and Navy, set about the establishment of the schools for the training of roentgenologists. Not only did this contribute toward better medical and surgical care of the soldiers and sailors both overseas and at home but undoubtedly that pioneer work placed roentgenology on the high road which you and I travel today.

WORLD WAR II

The wheel has turned full cycle. After the twenty-five years which have elapsed since World War I, it has again become necessary to mobilize our forces in a global war. We find ourselves fighting at one and the same time over the face of the earth in the same places where these little wars, which have just been described, and

Fig. 15. Use of airplane in transporting roentgen-ray equipment in World War II.

World War I were previously waged. Into these areas there has been carried by modern means (Fig. 15) roentgen-ray equipment (Fig. 16–23)* as up-to-date as the vehicles in which it has been transported—far removed from the coil, batteries and Crookes tubes that saw service in the previous campaigns in these countries.

* For additional illustrations of the roentgen-ray equipment used in World War II, see the article in this issue of the Journal by A. A. de Lorimier and Maxwell Dauer entitled "The Army Roentgen-Ray Equipment Problem."

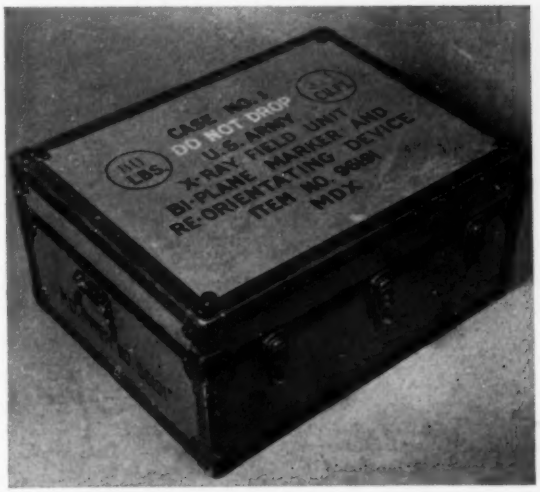

Fig. 16. Figures 16 to 23 show some of the roentgen-ray equipment used in World War II. These illustrations were kindly furnished by Colonel A. A. de Lorimier, Army School of Roentgenology, Memphis, Tennessee.

Manges[18] made a prophetic statement when he said, "In the event of another war involving our country, it is entirely probable that roentgenologists other than regular Army Officers would be needed; but it is also probable that special instruction in military roentgenology, if needed, would be given by regular Army Officers rather than by newly commissioned or reserve officers, as was done in 1917 and 1918, during the World War." Certainly Colonel de Lorimier and his corps of officers have rendered inestimable service to their country in the present war in mobilizing not only the equipment but the schools of instruction and training of personnel to meet the present emergency and he has from time to time presented to these two societies the progress of his efforts.

The advance of roentgenology over the intervening years has been such that its use in the examination of the chests of draftees is no longer debatable. We have seen millions of men inducted into the armed forces whose physical fitness was primarily established by the roentgen examination of the chest with the new units developed for mass survey.

Fig. 17

Since the mobilization and the quality of the roentgen-ray equipment in its medical usages in the present war is known to some extent to all of us, it was thought that it would be of interest to discuss its employment in another field which has become so vitally important because of the nature of

Fig. 18

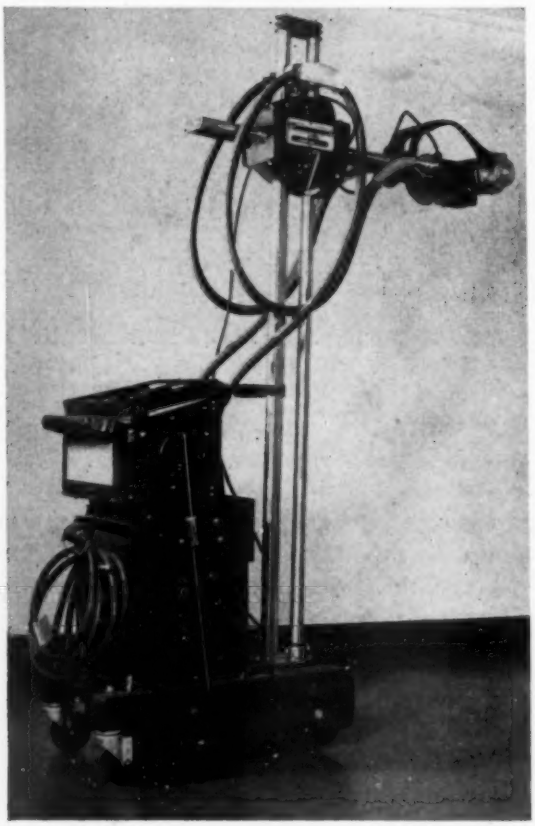

Fig. 19

the war we are waging. This field is the industrial application of the roentgen

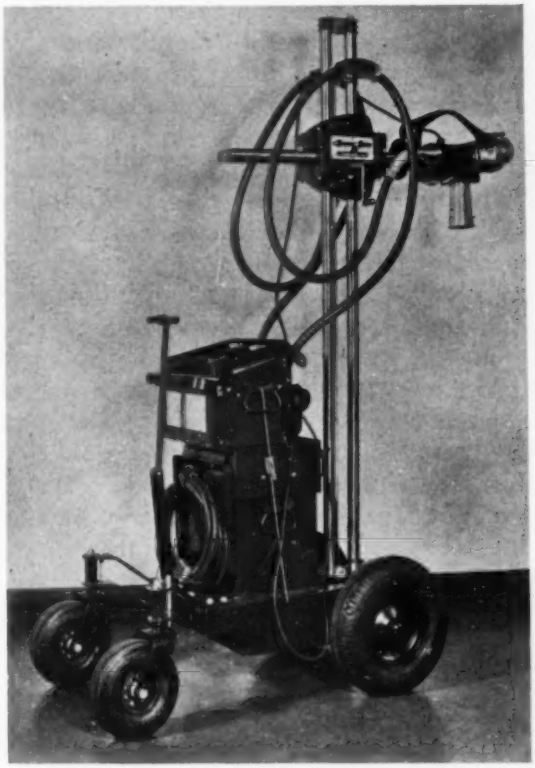

Fig. 20

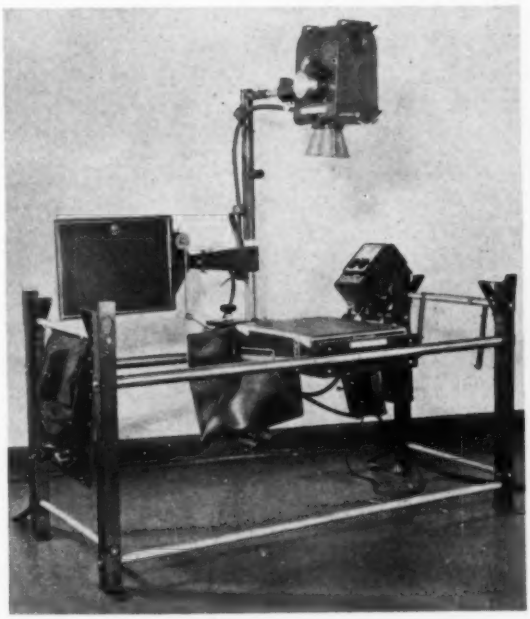

Fig. 21

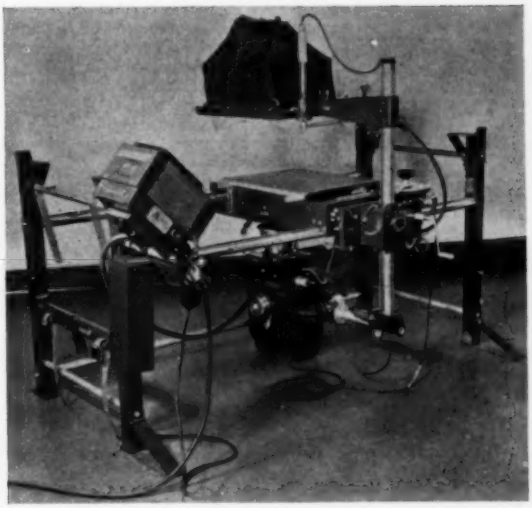

Fig. 22

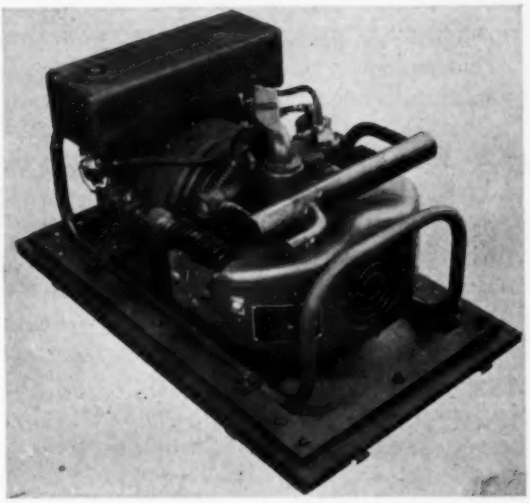

Fig. 23

rays. By testing the structures of the metals and the various materials used in military equipment, a service is rendered which brings the roentgen rays into the domain of preventive medicine through saving of countless lives which might otherwise have been lost as a result of defects in the essential parts of such equipment.

Historically, we find that the use of the roentgen ray in industry* is, like all phases

* We are indebted to John L. Bach and the General Electric X-Ray Corporation for many of the historical details of the use of roentgen rays in industry.

of sound scientific progress, the story of early recognition and then a long period of development which resulted in the efficient, shockproof, high power apparatus which is in use today.

Practical application of the roentgen ray in industry, while recognized early as having great possibilities, did not become an actuality until the advent of more powerful apparatus. This started in the United States in 1922 when roentgen-ray transformers, controls and tubes reached a degree of perfection which permitted the use of very high voltages. Continued technical improvement led to gradually increasing voltages until now roentgen equipment which operates at one to two million volts, with complete safety and precise control, is available.

One of the most important advances in roentgen-ray apparatus came with the development by Coolidge of the principle of immersing the roentgen tube and transformer in an hermetically sealed and grounded tank. This provided shockproof and climate proof operation, eliminated the need for high voltage cables, made possible unusually compact design and greatly increased the range of service for industrial roentgen units.

The first application of the roentgen ray in industrial roentgenography in this country was made at the Watertown Arsenal. It was here that much of the real pioneering work in the employment of roentgen rays for non-medical purposes was carried out and much was accomplished especially in demonstrating flaws in metal structures and determining their effects upon the ensemble of the structure.

The aluminum industry next—about 1927—adopted roentgen-ray equipment for a study of their products. Here was a preliminary step of most vital importance to the present program of war material production because roentgen rays have played an indispensable rôle in the development of aircraft. It was recognized early that all parts going into aircraft should be as light as possible and still provide the necessary strength. Aluminum, therefore, found a ready acceptance. But even with the light weight material, engine parts and structural members had to be designed for maximum strength with minimum weight—a job in which the roentgen ray served as an invaluable guide to results that can well be considered truly remarkable.

Later the roentgen ray entered another field. Leading manufacturers of high-pressure boilers wanted to eliminate riveted structures and adopt welding as a standard construction method. Welding up to that time had been considered simply as a convenient method of sticking two pieces of metal together. Little thought was given to the metallurgical considerations involved; nor was much time spent wondering if it would be possible for a welding operator to place weld metal free of the defects that would make welding practically useless in the boiler industry. Progressive, far-seeing manufacturers changed all that. They used the roentgen ray to examine completed welds, learned to diagnose defects and their causes and used roentgenograms to point out these defects, and the mistakes that caused them, to welding operators. The results were better welding and welds strong enough to meet the requirements for high-pressure vessels of many types. In some cases, modern practice required complete roentgen examination of welded seams and in others roentgen-ray inspection of weld samples provided a periodic check on the quality of work being done by the individual operator.

Welding has always carried with it one great disadvantage, in that the heat used for welding changed the nature of the parent metal. It has long been known that a weld, properly made, is stronger than the metal around it. Figure 24 shows one reason why this is so. Here we have a perfect weld but the armor plate has lost its tensile strength and cracked. At the top of the figure is a roentgenogram of the whole plate, in the center a roentgenogram of the

specimen after it was cut out and at the bottom a photographed section, four times enlarged, of the piece itself. Modern techniques have eliminated this source of failure.

So it is from the pioneer work done in the application of roentgen rays, first to heavy castings at the Watertown Arsenal and then to light metal castings by the aluminum industry and lastly to welding, that the tremendous benefits are being reaped in the present war production program.

A few examples of the applications of the roentgen ray in a variety of industries may prove of interest. In the Navy, roentgen-ray examination of the castings that go into turbines is an accepted routine; the welds and castings which go into high-pressure steam systems aboard ship are also roentgenographed, as are weldments in gun mounts. Army gun mounts and carriages too require roentgen examination, as do

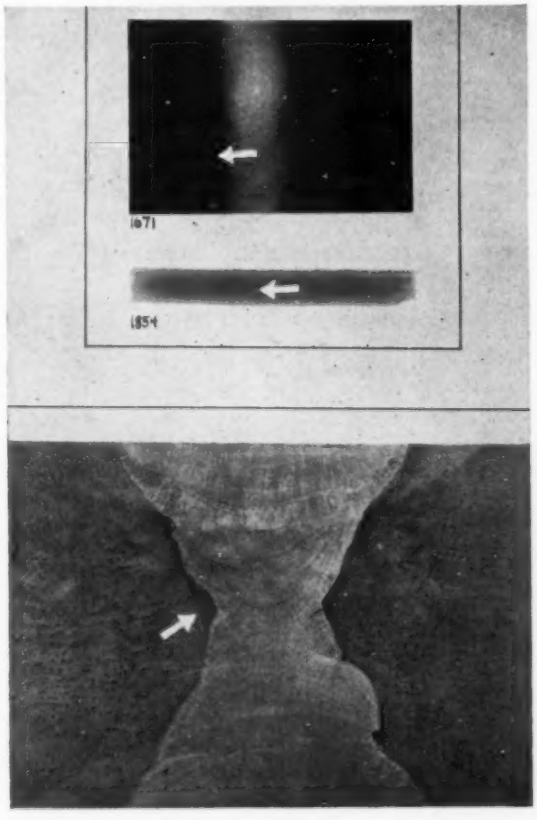

Fig. 24

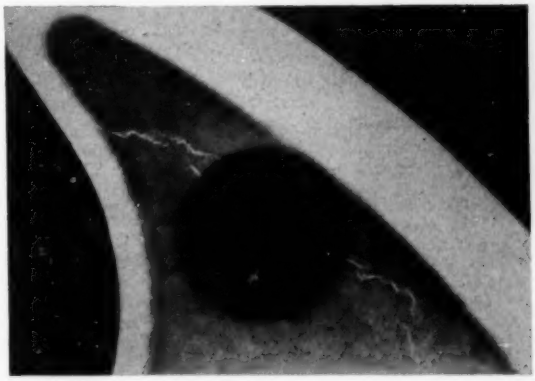

Fig. 25

certain parts of tanks and other heavy armament materials.

In the aircraft industry, many of the parts are so important that every one that goes into the airplanes is inspected by the roentgen ray.

In the examination of the various kinds and thicknesses of metal, different types of industrial roentgen units are used, operating at voltages ranging from 60,000 to a million volts and just recently a unit operating at two million volts has been made available. The production of these high voltage units has played an important part in the speeding up of vital war production and has cut innumerable hours and days off inspection time. In some cases it has reduced inspection time of a single large casting weighing as much as 50 tons from five days to five hours. These high voltage units are also important in increasing enormously the number of parts which can be examined.

In addition to saving the lives of our fighting men by the elimination of defective vital parts, a great amount of time and money is saved because the castings are examined in the rough before the final polishing is done. Thus if a defect is found, that part is discarded without the waste of further effort.

Obviously, all these roentgen demonstrations of flaws and defects in the densest metals are of inestimable value from the point of view of an enormously speeded up war program. However, it would be of a

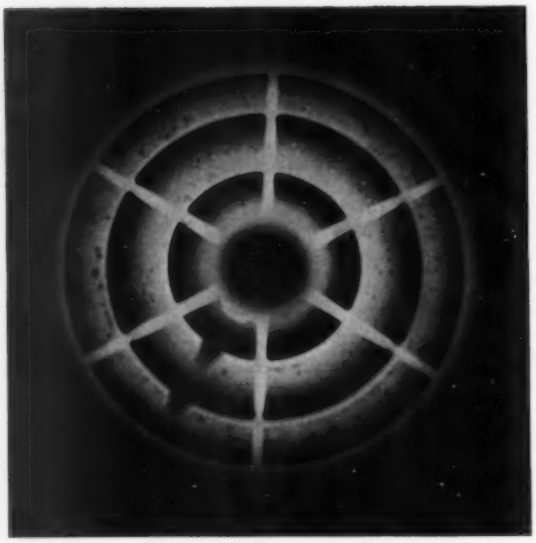

FIG. 26

still greater importance if means could be found to eliminate the cause of these flaws and defects at the source and thus develop methods for producing unprecedented numbers of perfect parts. In this battle of production which we have waged and won, with resultant saving of thousands of lives of our soldiers, the roentgen ray has again been our most important weapon. Only a very few examples can be shown at this time, but they illustrate how this was done. Figure 25 is a roentgenogram of an aircraft part cast of "duralumin." The bright line which traces an uneven course across the center of the film is copper which has frozen out of the alloy due to strain which occurred when the part cooled and contracted in the mold. By studying the flaw with the roentgen ray it was possible to map out the nature and direction of the strain, and find its cause, after which a simple change in the mold eliminated the trouble. Figure 26 illustrates the adaptation of an old method. This is a pre-war "diecasting" showing many flaws and holes beneath the surface. The method gives fast production but because of its faulty products it was used only for such things as door handles for automobiles. Figure 27 shows some modern diecastings. These are vital parts of military aircraft. Before the war these parts were machined out individually and it was believed that no other method could produce the needed precision and perfection. Total production, however, amounted to only a few hundred per year and thousands were needed at once. Experimental diecastings were made and their flaws studied by the roentgen ray. When the nature of these flaws was brought to light and it was shown that they always occurred in the same location, it was possible to make changes in the die and the technique which completely eliminated the flaws and made possible the production of perfect parts in any number desired.

Sand casting is a process of great antiquity, which up to the time of the war had not undergone any fundamental change. In sand casting, first a model, called a "pattern," is made of wood or wax in the shape of the desired piece. This pattern is imbedded in a box of sea sand to which has been added an organic binder such as molasses and an inorganic binder such as clay. Means are provided for getting the pattern out after the sand has set firmly around it. Molten metal is then

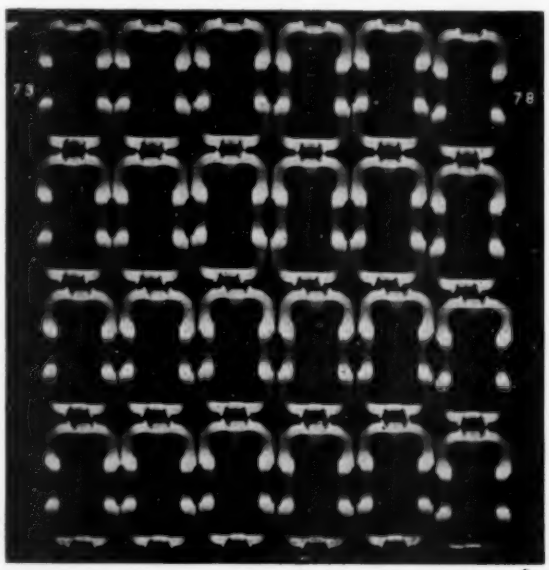

FIG. 27

poured in through a hole and cools in the shape of the original model. The process has always been used for producing the heavy parts of machinery and for such things as the motor blocks of automobiles, but in its ordinary form it is a process from which no great amount of precision can be expected. In addition, the surface of the casting is always rough and uneven and the method unsuitable for the production of parts having fine detail or deep grooves in their surfaces. All of this had to be changed, for sand casting is a fast method of production. It was changed. Experimental castings made with roentgen-ray control quickly showed that the porosity, gas pockets in the metal and the coarse grain structure of the metal itself could be eliminated, giving strength, and that the metal could then be made to fill in even the most intricate surface detail. Figure 28

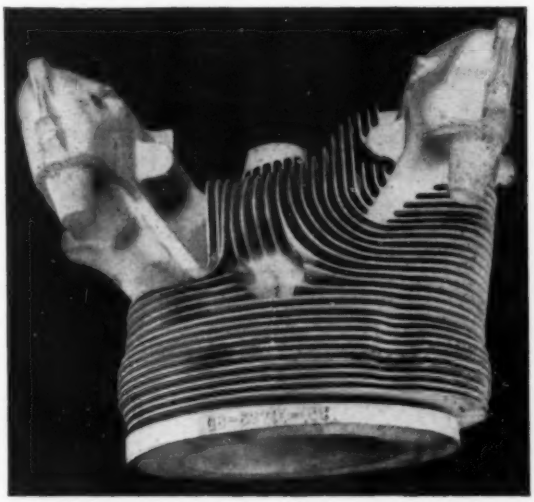

Fig. 28. Illustration courtesy of Don McCutcheon and the Ford Motor Company. By permission of the United States Army.

shows an aircraft cylinder head produced by present day sand casting methods after roentgen-ray research had eliminated the causes of trouble. Figure 29 illustrates a sand casting for an aircraft motor, in which at one point two waves of molten metal flowed together, in the casting process, trapping a layer of oxide between them.

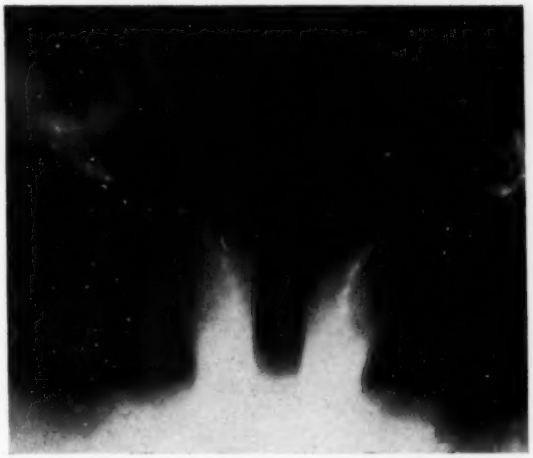

Fig. 29

The result was an occult flaw which allowed the part to pass all standard tests, but later, after it had been heated up a number of times, could open, and result in the sudden destruction of the motor. This flaw occurred at a point which could not be depicted by ordinary roentgen techniques and a special method, which we are not permitted to discuss at this time, had to be devised. Once it was discovered, its elimination was easy.

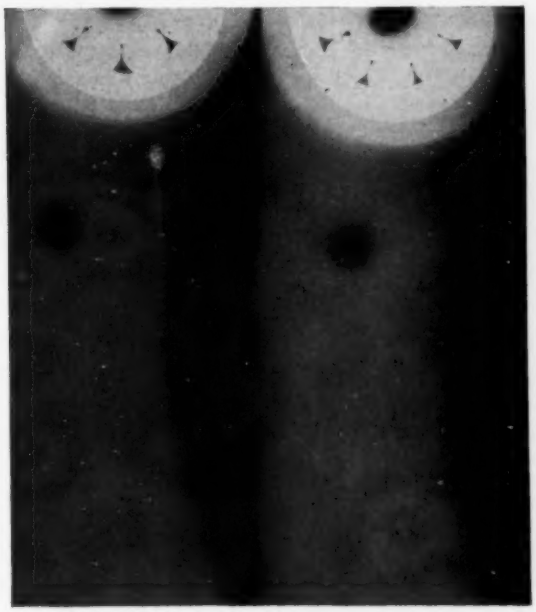

Fig. 30

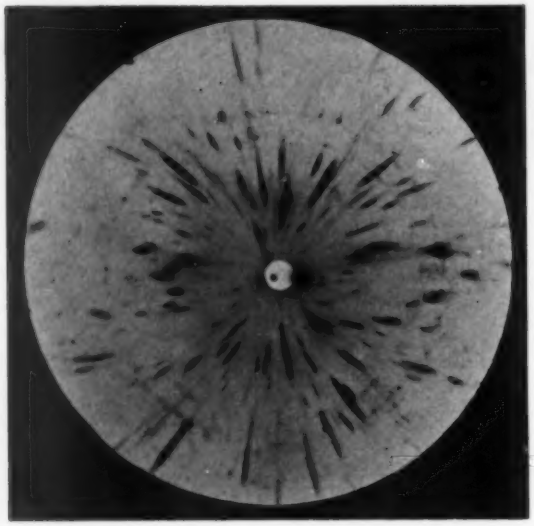

FIG. 31

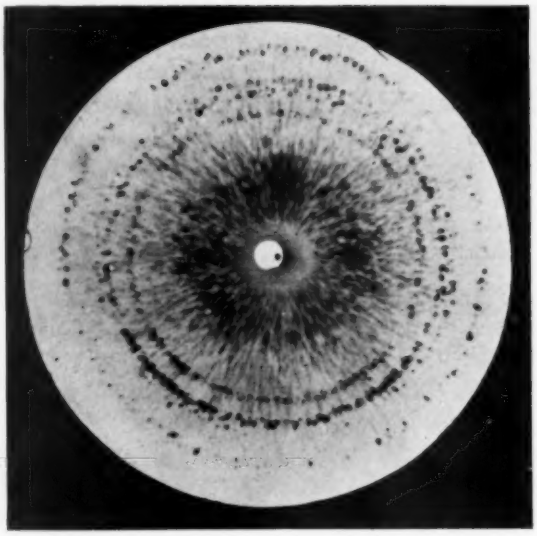

FIG. 32

Still, roentgenography is not the whole story in connection with industrial investigations and structural research. For some time now it has been necessary to lean heavily upon another roentgen-ray procedure which is based on diffraction. Originally diffraction studies were the special field of theoretical scientists, but before 1930 a patent had been granted to an American for the production of a new kind of rolled steel, far better and stronger than anything which had gone before, and this patent, together with the entire process was the product of roentgen-ray diffraction experiments.

The practical side of diffraction in this war is shown in the next few illustrations. Figure 30 shows a roentgenogram of a vital part of one of our Navy planes. From all possible roentgenographic evidence, this part is perfect. This roentgenogram was made early in the war and the piece shown had been made by the best forging process then known. However, planes equipped with this part lost their wings while in mid-air. When this problem came to the research laboratory, it was soon discovered what was wrong. By the diffraction method it was shown that the forging process had developed a crystal structure which was weak and fragile (Fig. 31). The forging process was then improved and Figure 32 shows that after the process was changed the part now has sufficient strength. The re-arrangement of the molecules can be seen.

A field no less important in which roentgen-ray diffraction has been put to use is the examination of quartz crystals which are so vital in all radio intercommunicating systems. There is enough quartz of proper quality in both North and South America but through glacial

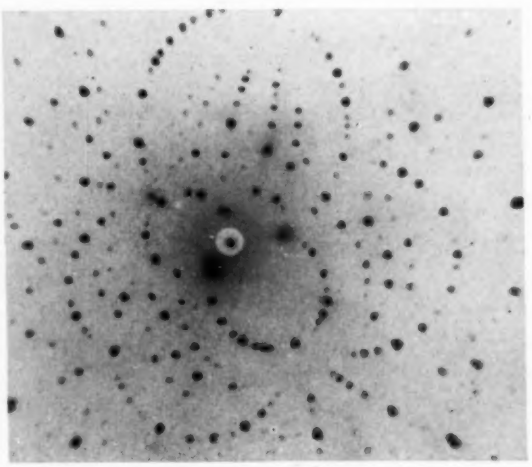

FIG. 33

action and other geologic catastrophies, these crystals have been ground down into shapeless masses and it was thought impossible to cut usable crystals from them. However Figure 33 illustrates how it was done. The rough piece of quartz was subjected to diffraction studies; a pattern such as this one showing the internal crystal structure tells immediately where the crystal axes lie and shows how to rotate the crystal to get the desired alignment. The crude piece of quartz is then cut into slabs at the proper angle with respect to its crystal structure and these slabs are then ground to proper precision for use.

These illustrate a few of the uses to which the roentgen ray has been put in industry in this global war. Time does not permit me to discuss the enormous aid which the roentgen ray has proved in such problems as the manufacture of synthetic rubber, silk substitutes, plastics, metal fabrication and a host of other problems.

Without soaring aspiration and without daring deed there is no science, no knowledge of nature. The conquest of a new region of knowledge resembles in many respects the occupation of virgin territory. First come the roadmakers, who unite a number of isolated points; then come the bridge-makers, who span many a yawning chasm; and last come the temporary shelters, which must ultimately be replaced by statelier buildings on deeper foundations and composed of more durable materials.[15a]

When once peace is established it is to be hoped that all of us will take the more durable materials that have emerged from the scientific efforts in these tragic years and bend them toward the uses for which they were primarily intended, namely for the betterment of mankind.

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THE ARMY ROENTGEN-RAY EQUIPMENT PROBLEM

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INTRODUCTION

WITH the recent world conflict at an end, there is a natural tendency to consider new avenues of interest; to look ahead and to forget the past. "There will be no more wars"—some may say. However, any army must not rest so complacently. Others, too, are thinking to the contrary and considering the distant future, when war may break out again. For such thinking, it seems practical to take some inventory of recent plannings and experiences and to record suggestions which might be of value in case another conflict is forced upon us.

There has been a marked change in the concept of roentgenological service requirements during mobilization and conflict; considering the viewpoints prior to the commencement of this last conflict, the provisions during the earlier months of it, and the activities of the last few years.

In particular, the demands for roentgenography were much more extensive than anticipated, either by personnel in the Army or by the roentgen-ray film industry.** Roentgenography has been required prior to entrance into the Service; it was extensively demanded with each hospitalization, and it was demanded even in the most forward installations where the original plannings had considered merely the use of roentgenoscopy.

PRELIMINARY PLANNINGS

It was clearly anticipated that this conflict would be fast moving; that fronts would be moved rapidly, ahead or to the rear. Therefore, it was considered impractical to depend upon the use of any roentgen apparatus at the most forward medical installations. The third echelon concerned with the care of battle casualties was the farthest forward installation at which roentgen-ray equipment and services were provided (i.e., the motorized Evacuation Hospital, or the forward elements of the Field Hospital). It was realized that the equipment should be of a design permitting easy assembly and disassembly, together with simplicity of operation and maintenance; ruggedness and dependability for all military requirements.

Each item was designed as two or more component units. Each component unit could be packed separately, with bulk and weight limited to that which could be carried by two men. There was set, as a goal, a weight limit of 200 pounds, for any one component (packed). Detachable small parts were avoided. Versatile adaptations were provided, for it was believed important that each item should be serviceable for any and all types of hospital installations. Specific types of equipment for one or another echelon seemed impractical. It was realized that the handling of this equipment should be largely reflex, and that it should not be necessary for the operator to deliberate and study in detail the sequence of operation of the controls. In particular, it was believed important that equipment utilized in the forward echelons should be familiar also to the personnel serving in the rear who might sud-

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** During the last several years of the conflict, it was necessary to ration and to limit the supply of films to the civilian profession. All film manufacturers were operating at maximum capacities; still many doctors and many civilian clinics suffered roentgenographic restrictions. The Army required approximately half of all film production.

denly be moved to the front. In this manner, the efficiency of transfer of personnel to other areas could be accomplished expeditiously with a minimum period of time required for adjustment to a fluid combat situation.

It was thought that roentgenoscopy should be most important; that otherwise there should be provision for a rapid method of foreign body localization and provision for roentgen therapy at least to the extent of handling infections and dermatoses. These believed-to-be essential fundamentals were provided with the roentgen-ray machine unit and the field table combination. Roentgenoscopy could be accomplished with the patient lying on the litter on which he had been placed when removed from the combat area. It could be accomplished with the patient recumbent, sitting, or standing. Roentgenography could be performed similarly. In connection with the adaptations for roentgenography, it was the original plan that films and processing equipment, together with chemicals pertaining thereto, would be provided only for the fixed type of hospitals. Foreign body localization, with respect both to the horizontal and vertical planes, could be accomplished with this equipment, within fifteen to sixty seconds and without the need for films or chemicals.[1]

The roentgen-ray machine was ordinarily utilized in connection with the field table. Depending upon the demands of the roentgenologic situation and to provide for use of the unit for ward work, a mobile chassis was designed. The earlier mobile chassis was equipped with small caster-type wheels for supporting the base. With the increase in the range of roentgenographic activities over all sorts of rough ground and improvised hospital buildings, this chassis was modified and equipped with large pneumatic rubber tires.

A special tent was developed having lightproof characteristics. Double purpose features were provided for it, also. The front curtains of it could be arranged to permit easy ingress or egress, such as would be required for roentgenoscopy. Otherwise, the curtains could be adjusted to provide for a labyrinth arrangement, thereby rendering it practical for the processing of films. The supporting structure of the tent was such that it was possible to set it up in any area that might be available. It could be used inside a room, an underground tunnel, inside a larger hospital tent, or set up by itself on the outside.

A combination film dryer and loading bin was also developed. It was designed in two sections in order to permit easy handling. The item was so arranged that it was possible to use it with the smallest type of hospital, and with multiples of the item, it was still practical for the largest installations that might be established.

In connection with the requirements for roentgenography, there was provided a film processing unit designed in accordance with the basic principle of minimum weight and flexibility of installation. This item consisted of a master chemical section and an auxiliary wash section. Each of these contained a tank and a pedestal. In the case of the master chemical section, the tank permitted the use of insert tanks, the size of which depended upon the type of hospital installation with which it was used. Its pedestal section served to circulate water from the main tank into the heating and/or cooling compartment (the elements of which were thermostatically controlled). The auxiliary wash section served to expand the processing accommodations. In appearance, it was similar to the master chemical section and had the same physical dimensions and capacity. However, its pedestal unit did not contain the components for water circulation, refrigeration, and/or heating. Water connections with these items could be made to a community water supply or continuous circulation of a bucket supply of water was possible.

A specially designed gasoline-electrical generator was provided in order to serve as a dependable source of 60 cycle, single-phase, alternating current. The ordinary type of commercial generator, of capacity

below 5 kw. was not suitable for the roentgen-ray machine itself. Distortions in wave form, line surges and inefficient governor control were some of the common shortcomings. Conventional generators were not designed to handle the sudden fluctuations of load, such as produced by energization of the apparatus; having sudden fluctuations of load and utilizing only half the wave (i.e., except for the smaller loads concerned with heating of the filament). The generator that was finally provided was the result of a careful analysis* of the requirements of the roentgen-ray machine; it possessed the characteristics necessary to minimize tube and cable failures.

These were the initial problems; problems such as those previously described.[2] Conventional commercial equipment was to be supplied to the installations located in the Zone of Interior.

SHORTCOMINGS WITH RESPECT TO MATERIALS

During the early phases of construction, materials of all sorts were available. Aluminum and lightweight alloys were used extensively, and thereby weights were held at a minimum. Within the first year of large scale construction, shortages of the proper types of material produced a very definite problem. The Medical Department was no longer allocated the use of aluminum. As a consequence, re-toolings were required of the manufacturers and, in some instances, changes in design were necessary. Equally disturbing was the fact that weights were increased (several items which previously weighed below the 200 pound limit were increased 25 to 30 per cent in weight).

At the height of the manufacturers' production schedule, many important parts became highly critical; at times, almost unobtainable. This applied particularly to the electrical components: meters, special switches and relays, power cables and wirings.

* Again particular credit is recorded for the special interest, and ingenious assistance provided by Mr. E. R. Goldfield and the Picker X-ray Corporation in the designing of this item.

LARGE SCALE REQUIREMENTS SATISFIED

All manufacturers were invited to cooperate with the Army in these developments. Some of them manifested particular interest in one item; some, in another. Contract awards were based upon special facilities and competitive biddings.

It was advantageous to the Army that one manufacturer obtain a contract for the construction of all the units of one particular type. This provided more definite assurance that there would be complete and easy interchangeability of replacement parts. At the same time, it appeared practical and desirable that the greatest possible number of qualified manufacturers be engaged in the overall procurement program. This policy was not only equitable to the manufacturer, but it insured expeditious, continuous and efficient supply.

Regardless of the large quantities of apparatus required, practically all of the production schedules were completed on time. The manufacturers cooperated in a most meticulous and enthusiastic manner; the utmost of engineering skill was exercised, and many ingenious innovations were incorporated into the various items finally produced. Consultations were exchanged back and forth between representatives of industry and the Army. Unfortunately, there was not sufficient time to permit the testing of pilot models under actual or simulated field conditions. By informal arrangements, many unpredictable "bugs" were detected and eliminated just as soon as they became evident during the early stages of actual construction. In addition, a considerable amount of valuable constructive criticism permitted correction of defects as they became apparent as the first few units were placed into operation.

During the phase of preliminary plannings, an effort was made to ascertain the approximate quantities of each item which would be required. This information was of extreme value to the manufacturer, inasmuch as it would permit him to plan and arrange his facilities to the advantage of all

concerned. Various estimates as to the quantities required were suggested, but there was so much variation in these estimates that it was only possible to offer, at that time, statistics that were based primarily on probabilities. The following listing is therefore recorded so as to more definitely estimate the need in the event of a future mobilization:

Item No.	*Name of Item*	*Manufacturer*	*Quantity Supplied*
9605500	X-ray field unit, dryer and loading bin combination: Complete with air circulator; for field processing unit	Buck X-Ograph Co.	1,966
9606000	X-ray field generator: Gasoline powered, to produce approximately 2,500 watts. Complete in chest	D. W. Onan & Sons	6,530
9607000	X-ray field unit portable grid: Replacement grid for 9614500; also suitable for use in bedside or similar type of roentgenography.	Liebel-Flarsheim Co.	1,441
9608508 (110 volt) and 9608510 (110–220 volt)	X-ray field unit, machine, x-ray, 60 cycle: Consists of 1 each of 9608600, 9608700, and 9608808	Picker X-ray Corp.	
	Transformers		8,985
	Controls		9,035
	X-ray tubes		12,056
	Cables		20,380
9609005	Chest MD X-1, old type: Tubestand and chassis for converting 9608508 or 9608510 to a mobile unit; rear wheels 8 inch diameter, front wheels 4 inch diameter	Picker X-ray Corp.	3,706
9609010	Chest MD X-1, new type: Tubestand and chassis for converting 9608608 or 9608510 to a mobile unit; rear wheels 15 inch diameter, front wheels 10 inch diameter.	Picker X-ray Corp.	868
9611500	X-ray field unit processing unit, for darkroom: for film processing	Westinghouse Electric Corp.	2,311
9611700	X-ray field unit processing unit, auxiliary wash tank	Westinghouse Electric Corp.	1,000
9614500	X-ray field unit table unit: for field fluoroscopy, foreign body localization and roentgenography. Complete in chest	Westinghouse Electric Corp.; H. G. Fischer & Co.	2,811 875
9619100	X-ray field unit, bi-plane marker and re-orientating device	Westinghouse Electric Corp.	1,898
9621500	X-ray field unit, fluoroscopic, foreign body localization, complete: With table unit. Shockproof 15 ma. machine for use with both 110 volt and 220 volt current; 1 pair of gloves, 1 apron and 1 pair of goggles included with each assembly	Picker X-ray Corp.	1,588
	Wafer grids having an approximate dimension of 14×17 inch overall and with a 30 inch focal distance, as designed to fit the heavier field table as supplied by Westinghouse and Fischer	Liebel-Flarsheim Co.	3,066
	Wafer grids approximately 12×16 inch focal distance, to fit the Picker Airflow Unit (9621500)	Liebel-Flarsheim Co.	1,724

SHORTCOMINGS WITH RESPECT TO POLICIES

Contrary to the original plannings (and contrary to the practice during World War I) roentgenoscopy did not supplant roentgenography even in the most forward echelons. Films, film storage, and film processing equipment, chemicals, and darkroom facilities were demanded and sup-

plied even in the motorized Evacuation Hospitals and the forward elements of the Field Hospitals. Graphic evidence and permanent records, such as the roentgen-ray film, were believed necessary. The doctors of this war had become roentgenologically conscious. The surgeons wanted to see the roentgenograms. Many of the roentgenologists consoled themselves with the expression that "roentgenoscopy produced a bottle-neck in the handling of the patient, anyway." Even for foreign body localization, anteroposterior and lateral film studies, regardless of distorted anatomical relationships, were preferred by many to the more accurate and more rapid roentgenoscopic foreign body localizations.

Roentgenologists requested a rigid table top; they asked for equipment to permit easier handling of the patient for *roentgenography*—even though it did require moving the patient from the litter to the table top and then back from the table top to the litter. They asked for a moving "Potter-Bucky" diaphragm—for many thought that the factor of *movement* of the grid (versus grid ratio) was the all important factor concerned with clean-up of scattered radiation and fogging.

Some requested a field type of stereoscopic cassette changer. Others requested a field stereoscope. Some wanted a field unit having a capacity of 100 milliamperes (as compared with the 30 ma. provided with the standard type of x-ray field unit). Many of these requests were based upon the inability of the commercial designs of equipment to withstand the rigors of field conditions and also the considerable weight which characterized many of these items. In addition, there were numerous requests for various types of roentgenographic auxiliaries: tunnel changers, spot film and serialographic devices, angulation boards, etc.

MORE RECENT DEVELOPMENTS

In order to provide for some of these wants, the Army School of Roentgenology continued with research efforts, throughout the Emergency; developing items for the immediate requirements of the conflict and formulating plans for a long-range program.

Constructions and reconstructions were made of a field packing chest having a design such as to provide for converting it into various items of office furniture suitable for a temporary field roentgen-ray department. Packing chests had been provided for all items which were originally intended to be used with mobile installations. Other equipment was simply crated. This was the case for the combination film loading bin and dryer, and also the film processing units—the master chemical section and the auxiliary wash section. These items were shipped from the manufacturer in ordinary packing crates.

It seemed impractical to provide a packing chest for each component of these items. Instead, in order to simplify the problem of supply, the handling, and the shipment, the ideal arrangement appeared to be that of a single chest. The inside dimensions of this chest were such as to permit accommodation of any of the above mentioned components—the film loading bin, the dryer, the master chemical tank (of which there were two styles: the compact stainless steel type and a larger bulky wooden type); the pedestal section for the master chemical tank; the auxiliary wash tank (of which there were two styles: a compact stainless steel type and a larger bulky wooden type); and the pedestal section for it. Internal bracings, fixation straps and supporting panels served to secure these items irrespective of the variations of dimensions of the items. In most instances, there remained some space for additional packing of films, chemicals, linens, and other miscellaneous items (Fig. 1*a*, 1*b*, 1*c*, 1*d*, 1*e*).

After this chest was unpacked, it could be converted into one or another of the following items: desk, table, settee, bookshelf, clothes rack, storage cabinet, reserve water tank (90 gallons), or auxiliary wash tank. For the latter two adaptations, there was provision for making connections to community plumbing (Fig. 2*a*, 2*b*, 2*c*, 2*d*, 2*e*, 2*f*).

FIG. 1*a*

FIG. 1*a*. Packing chest for accommodating Field Processing Equipment.

FIG. 1*b*. Dryer accommodated in the bottom section of packing chest—top section removed. Note strap fixation.

FIG. 1*c*. Processing tank packed in lower section of chest—top section removed.

FIG. 1*d*. Loading bin packed in lower section of chest—top section removed.

FIG. 1*e*. Pedestal portion of processing tank packed in lower section of chest—top section removed.

FIG. 1*b*

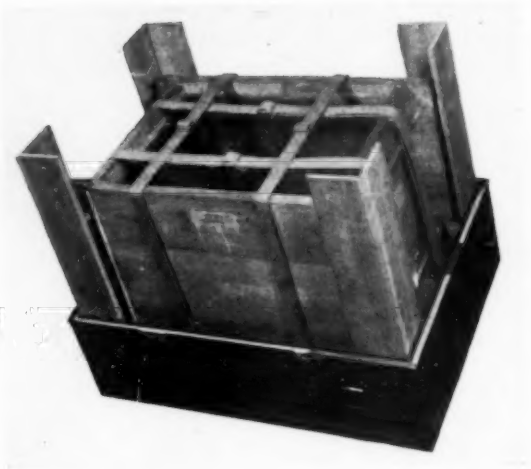

FIG. 1*c*

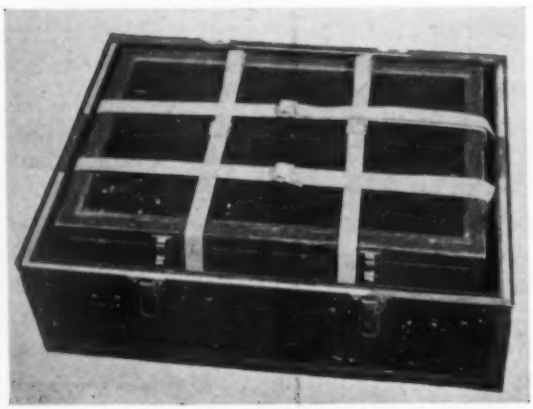

FIG. 1*d*

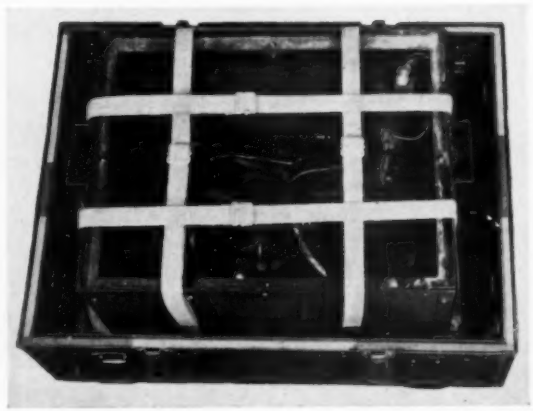

FIG. 1*e*

Fig. 2*a*

Fig. 2*b*

Fig. 2*c*

Fig. 2*d*

Fig. 2*a*. Bottom section of chest used as a table.
Fig. 2*b*. Top section of chest used as a desk.
Fig. 2*c*. Bottom section utilized as bookshelf.
Fig. 2*d*. Top section utilized as a storage cabinet.

With the assistance of H. G. Fischer and Company, Chicago, Illinois, there was developed a stereoscopic cassette changer, of the field type. The design was such as to permit it to be set up in a few moments' time. It was possible to use it either with the field roentgen-ray equipment or with any other standard design of equipment. There was provision for release of the cassettes by remote electrical control (Fig. 3).

FIG. 2e. Top section utilized as a clothes cabinet.

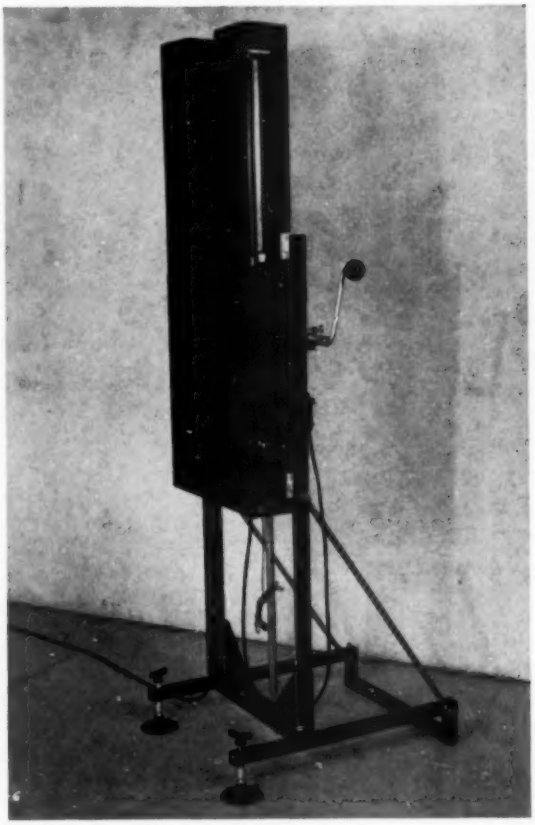

FIG. 3. Stereoscopic cassette changer.

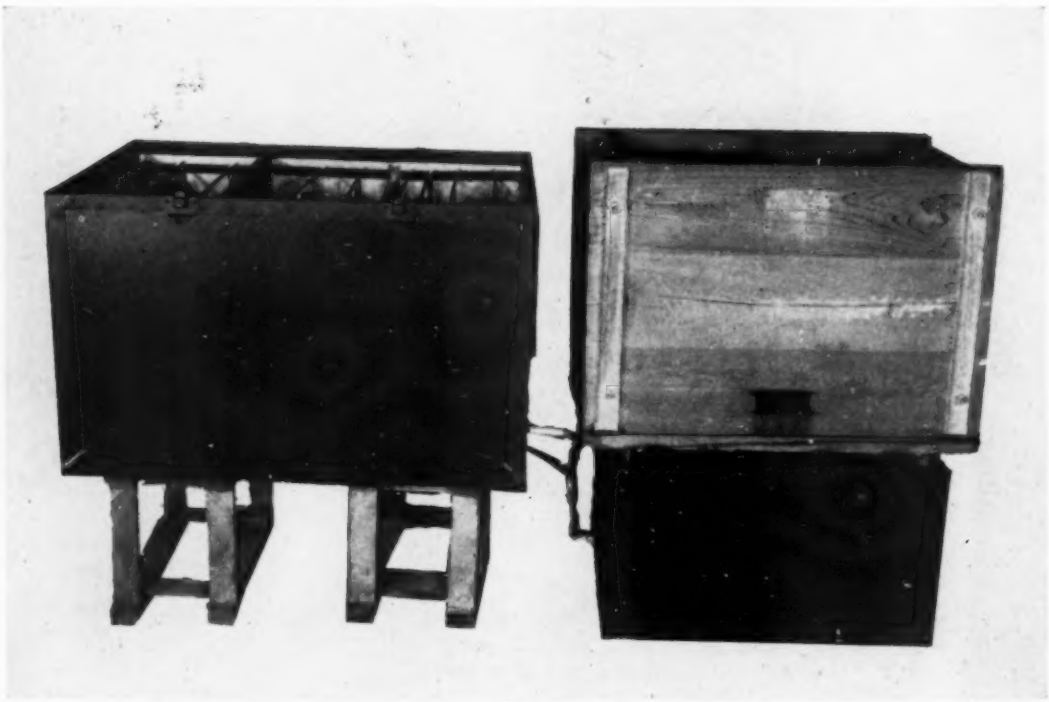

FIG. 2f. Top section used as a wash tank. Note arrangement of interior for baffle wash of films and connection to processing unit.

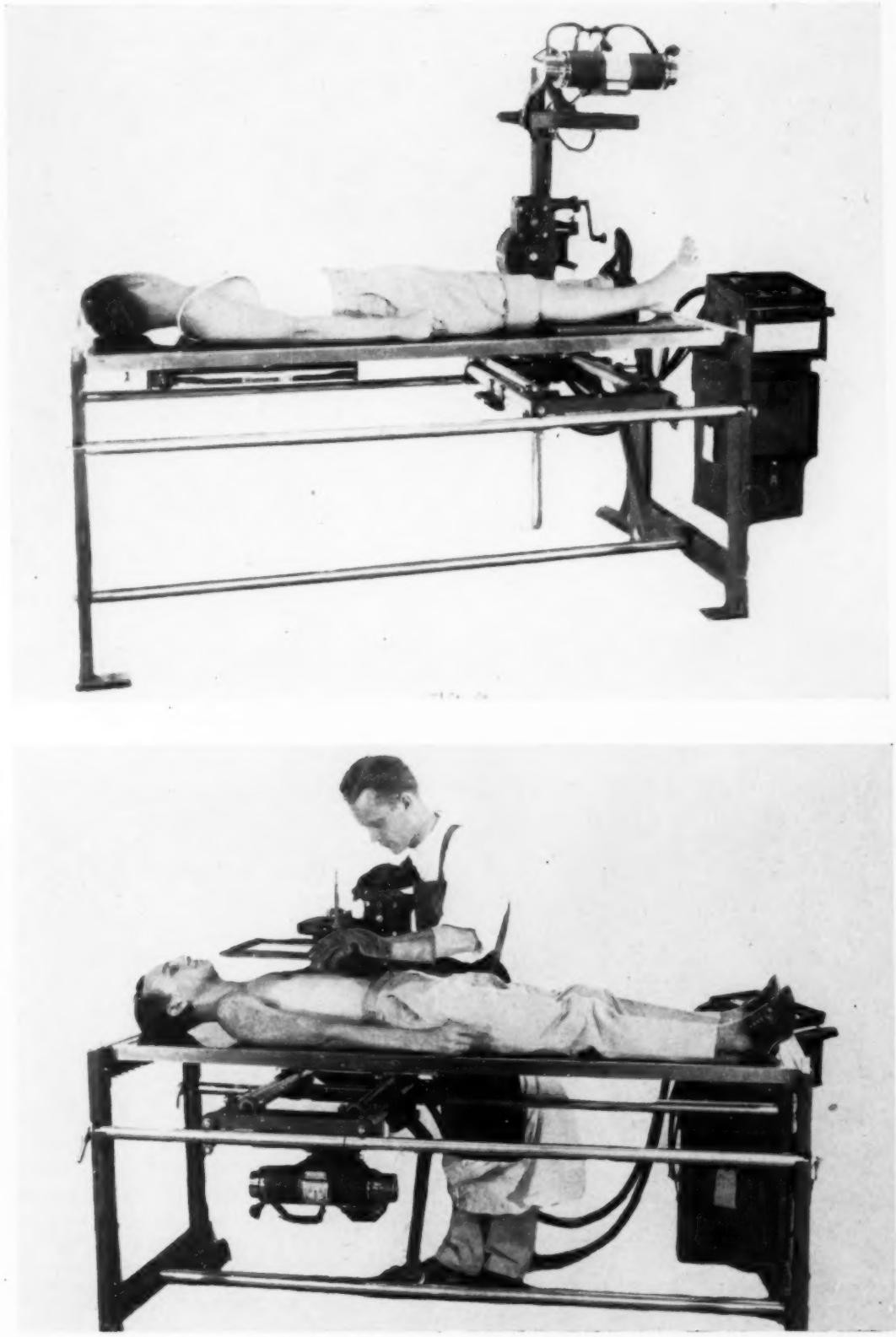

Fig. 4*a*. (*upper*) Solid table top used in conjunction with field equipment for horizontal roentgenography.
Fig. 4*b*. (*lower*) Table top positioned for horizontal roentgenoscopy and foreign body localization.

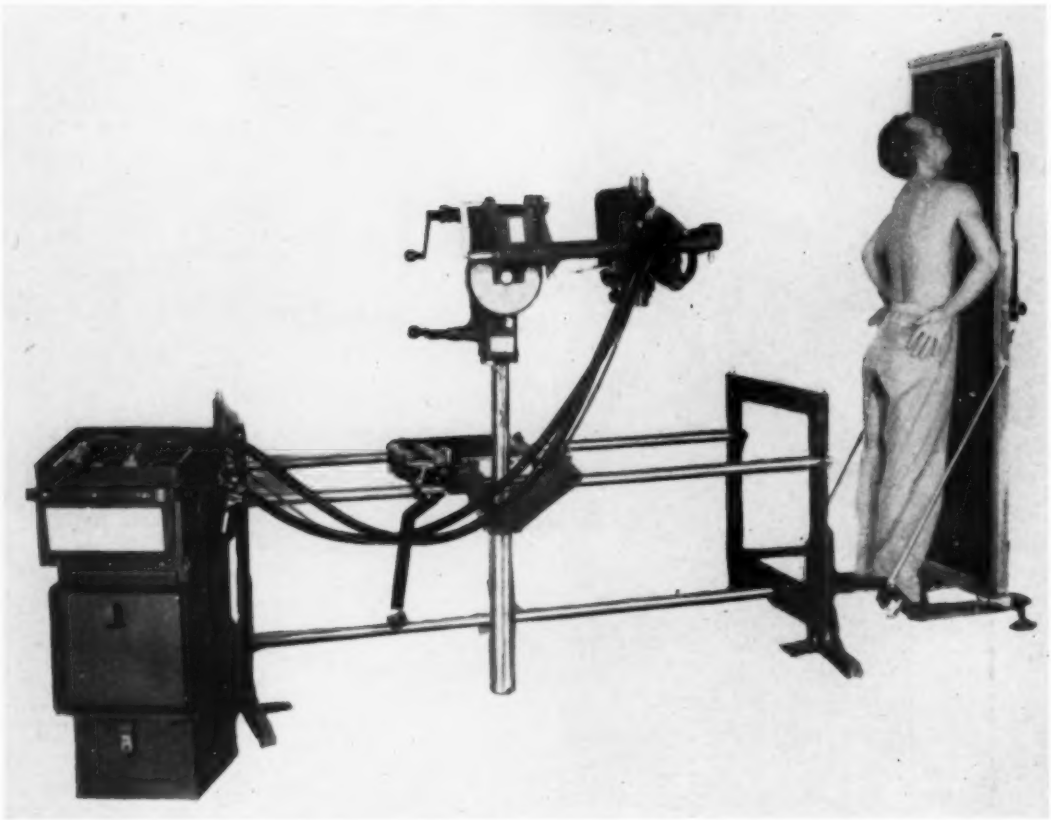

FIG. 4*c*. Table top positioned—at either end of the table—with Potter-Bucky diaphragm for vertical roentgenographic studies.

Solid table tops were constructed by the Picker X-ray Corporation and also by H. G. Fischer and Company. In both instances, Potter-Bucky diaphragms were incorporated. The removability of this table top permitted various adaptations for roentgenoscopy and roentgenography and it also permitted direct placement of the patient and litter, as originally planned (Fig. 4*a*, 4*b*, 4*c*, 4*d*, 4*e*).

A combination spot film and serialographic device with auxiliary components was constructed. This item consisted of a main tunnel housing and auxiliary attachments designed to permit a single, compact unit to be convertible into any of a number of accessory aids. It was designed essen-

FIG. 4*d*. Table top positioned for vertical roentgenoscopy.

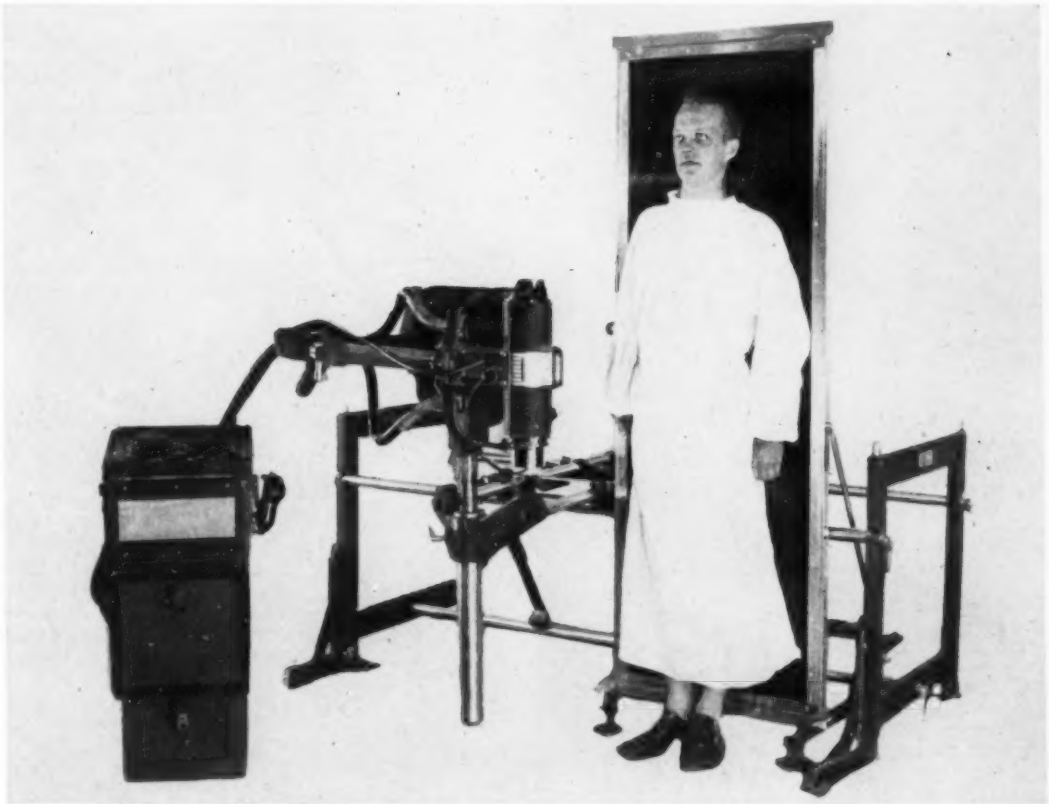

Fig. 4*e*. Table top positioned for vertical roentgenography—at any of the four sides of the table.

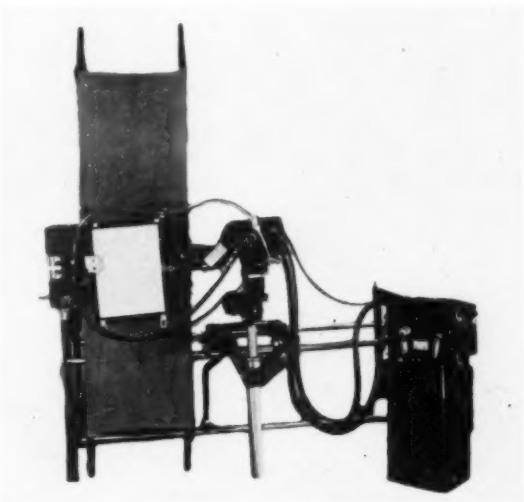

Fig. 5*a*. (*above*) Combination spot film and serialographic device attached horizontally to fluoroscopic screen for use in vertical roentgenoscopy.
Fig. 5*b*. (*right*) Device attached vertically to the screen for use in vertical roentgenoscopy.

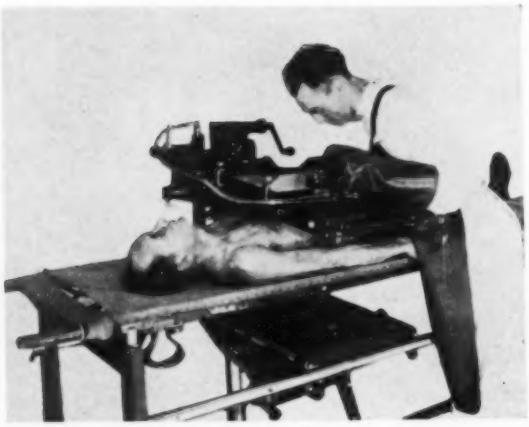

FIG. 5c. Device attached to fluoroscopic screen for use in horizontal roentgenoscopy.

FIG. 5d. Device used as a tunnel changer or stereoscopic cassette changer at the bedside.

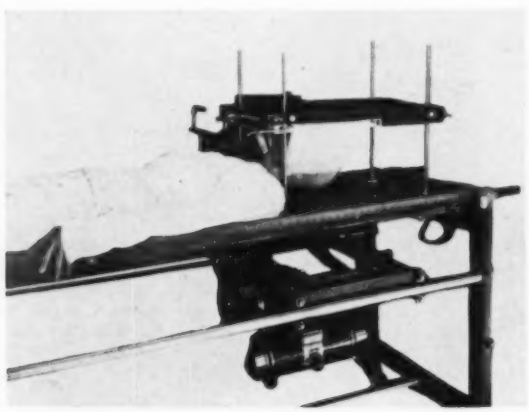

FIG. 5f. Device used for tube under-the-table roentgenography. An arrangement practical especially for maxillofacial fractures.

FIG. 5e. Device used as an angle board.

FIG. 5g. Device used as a kymograph. (A special grid could be inserted for this purpose with a change-over plunger provided for connection of the cassette carrier onto a cable moving mechanism.)

tially for operation in conjunction with the field roentgen-ray equipment. However, it could also be utilized with other types and designs of standard apparatus. In addition to its adaptation for spot film and serialography (incorporating an automatic change-over circuit for boosting the roentgen tube current from a roentgenoscopic setting to a roentgenographic setting), it could also be used as a stereoscopic cassette changer, tunnel changer, angulation board, for tube under-the-table roentgenography, and as a kymograph. This device was of course intended for large hospital installations (Fig. 5*a*, 5*b*, 5*c*, 5*d*, 5*e*, 5*f*, 5*g*).

Finally, the Picker X-ray Corporation developed a four-valve, full-wave rectification component which could be adapted to the standard field roentgen-ray machine. By this means, it was possible to increase the capacity of the unit from 30 ma. (half-wave) to 100 ma. (full-wave). It was also possible, with this arrangement, to recon-

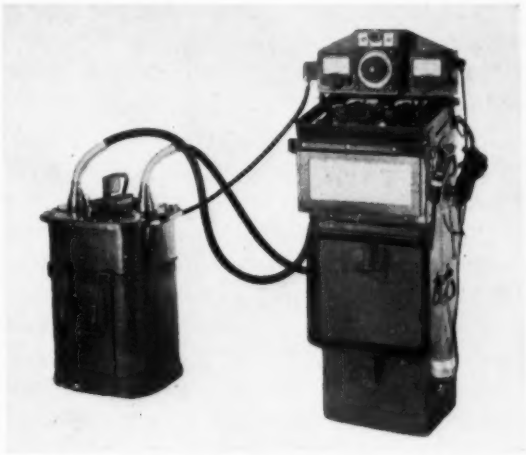

Fig. 6*a*. Close-up of rectification tank and conversion meter unit connected to the field unit to provide four-valve full-wave rectification.

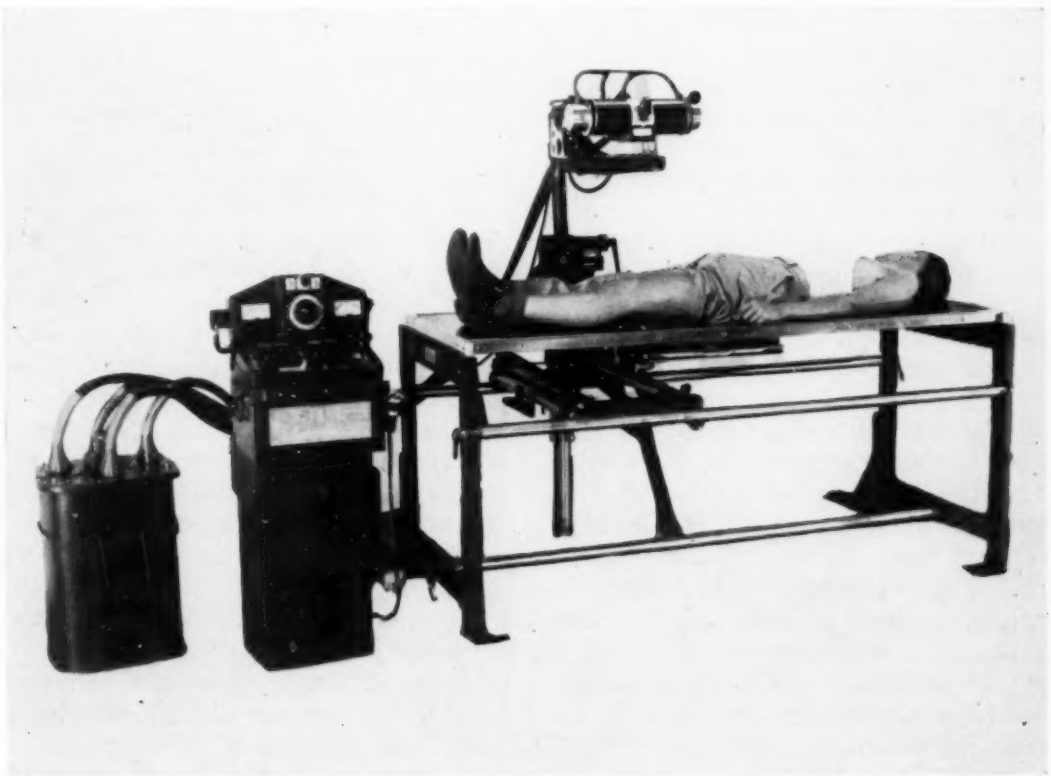

Fig. 6*b*. View of four-valve rectification component operated in conjunction with the field roentgen-ray unit, table unit and rigid table top.

vert the unit to 30 ma. if desired. The model was extremely compact, simple to operate, and rugged. It was contemplated that with the use of this component it should not be necessary to include as standard items any of the commercial high milliamperage table units—equipment which, because of its bulk and weight had been found to be very impractical for transportation and installation at scattered Army hospitals.

SUMMARY

When charged with the planning and development of roentgen-ray equipment suitable for wartime conditions throughout the world, as experienced during the past mobilization and conflict, meager information was available as to the desirable military characteristics of each item of equipment and the quantities of such equipment which would be required to fulfill the demands. With consideration of possible future responsibilities for military planning, there were recorded certain axiomatic principles which have dominated past developments. The quantity requirements of the basic items, such as concerned with World War II, are cited and there are mentioned here certain shortcomings and suggestions.

Specially constructed equipment should not be necessary when the outbreak of war appears to be imminent. The evolution of the design should be gradual and should permit the trial of a few items at a time and thereafter improvements should be made in such items based upon field and fixed hospitals, testings and recommendations. Modern innovations providing mechanical and electrical improvements should be tested and, when practical, they should be incorporated into the strictly Army equipment. In this manner, gradual improvement can be made of any basic item and then there will be assurance that there will always be available a design of proved performance possessing the very finest of engineering developments.

It should not be necessary to have one design of equipment for one type of hospital and a different design for another type of hospital. There should be a standardized line of equipment possessing the required military characteristics permitting it to function under all kinds of terrain and climatic conditions throughout the world. To fulfill this plan, there should be a basic component around which all other components will function. The basic component should be the nucleus. It should be easily portable. It should be rugged. Used alone or with auxiliary components, it should serve the gamut of roentgenologic requirements. It should be possible with this basic component to expand milliamperage capacities and adaptations merely by adding multiples to it or by the addition of simple accessories or attachments. Conventional commercial equipment should not be procured for use where it will be required to function under field conditions. Such equipment should be restricted for those installations where the facilities are similar to those of civilian institutions. There would be an ever constant and progressive development of a strictly military line of equipment. This line of equipment should be inclusive not only of basic items, but also of auxiliary apparatus.

Each item in the military line of equipment should be made up of components easy to assemble or disassemble. There should be no loose or detachable small parts which could be easily lost or misplaced under changing field conditions. No items should be designed to fit into a packing chest. Rather, the equipment should be designed first to accomplish its purpose, and then the packing chest developed to accommodate it. The packing chest should have dimensions which would permit it to be easily packed and transported with other chests. The dimensions and sizes of these chests should be kept to an extreme minimum compatible with requirements. The packing chests should provide for the greatest possible range of adaptation for use when the equipment is unpacked. It should be possible to convert the packing chests into field furniture and hospital office equipment. The chests should be

waterproof, dustproof, and permit fungiproofing, moistureproofing and corrosion treatment of the subject items included within.

Electrically, the equipment should be designed to operate from either community supply or portable generator sets. They should be able to utilize voltages in the 110–250 volt range and possibly 440 volts at 50–60 cycle, alternating current, single-phase. When extreme portability is required, a combination electrical generator and roentgen-ray unit designed for 400 cycle operation might be practical.

In connection with the basic components, there should be developed a complete assortment of auxiliary aids with provision for adaptation without the use of special tools. Here again, single purpose items should be avoided. Every effort should be exercised to provide multiplicity of purpose to the extent of including, two, three, or a half dozen functional adaptations. Some caution must be exercised in this regard, however.

The mode of roentgenologic practice cannot be anticipated. At the present time, the greatest emphasis is directed toward roentgenography; roentgenography versus roentgenoscopy. As group practice, socialization, regimentation and legal medical practices continue to expand, it seems quite likely that there will be continued desire for permanent, graphic film records; roentgenography and repeated *roentgenography* of most patients.

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THE HISTORY OF DOSIMETRY IN ROENTGEN THERAPY

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ROENTGEN rays have become a very important agent in medicine. The possibility of influencing living tissues by their action was recognized within a few months after their discovery and in the early years a considerable amount of more or less casual and empiric therapy was attempted. Some patients were found to be benefited, in others no good was accomplished and sometimes actual harm seemed to result. When a favorable effect had been obtained in one case, there was no assurance that the treatment which produced it could be repeated. Tubes and generators were very irregular in behavior, and little or nothing was as yet known of the significance of the various physical factors. It was evident that some means of measuring dosage was essential before real progress could be made.

The first attempts by physicists to measure radiations had little bearing on the dosage problem. Dorn (1897), using an air thermometer,[17] and Rutherford and McClung (1901) with a bolometer,[80] attempted to determine the total energy emitted by a roentgen-ray tube or a radium source. The use of such instruments was not practical for the therapist, and there appears to have been no early effort to adapt them or to employ other physical means.

The first definite scheme for dosage measurement was proposed in 1902, and ever since then, radiologists and physicists have sought to develop more satisfactory methods. Much research has been directed toward finding accurate, simple, and practical units and standards, and means of employing them. A great deal has been accomplished, but the problem is still not completely solved.

Among the first biological reactions to be observed were the production of erythema and epilation. The value of the latter in the treatment of ringworm of the scalp was at once evident, provided it could be assured that the epilation would be temporary. It was the need of establishing such assurance that led to one of the first attempts at quantitative measurement of roentgen-ray dosage, the pastille radiometer.

Pastille Radiometers. In 1902, Holzknecht,[46] utilizing the knowledge that certain chemicals underwent color changes under the action of roentgen rays, offered the first dosage measuring instrument, which he called a chromoradiometer. It consisted of a graduated color scale and a series of capsules filled with a solution whose composition was not made public. However, its behavior was not satisfactory and it was soon withdrawn from sale.

In the next two years, other color changes were tested, but nothing practicable was devised until Sabouraud, in 1904, thought of using the color change which had been demonstrated when the platinocyanide of barium was exposed to roentgen rays. In collaboration with Noiré, he devised a very simple radiometer for the one purpose of indicating when an epilating dose had been administered.[81] The standard was a card carrying two colored disks. One, a brilliant green, was the color of unexposed pastilles of the cyanide, the other an orange color, was the shade assumed by a pastille placed half way between the skin and the tube target, when an epilating dose had been delivered at the skin. In practice the pastille was put in the half-way position, the tube operated for a time thought to be less than sufficient, the test pastille compared with the standard, and this intermittent irradiation carried on until the test piece showed the desired change. For the

determination of this one dose, with a fixed quality of radiation, the instrument was satisfactory. However, it had no sort of graduated scale for determining fractions of the full dose. Furthermore, its readings were affected by changes in the quality of the radiation, hence it was of limited applicability.

Bordier, Holzknecht, Hampson, and others,[8,40,47,49] soon developed radiometers with graduated color scales, so that known fractions of the epilating or erythema dose could be administered. Of these, the most successful and widely used was the improved model of Holzknecht (1910). The standard color index was a celluloid band 4½ inches long, colorless at one end, and shading gradually through orange to deep brown at the other. Beside this was a band of colorless celluloid. The pastilles were mounted on small strips of cardboard; for each test one was exposed and another used as control. After the exposure the pair were inserted into the frame so that two semicircular pieces were in contact to form a complete circle. The exposed semicircle was under the colorless strip of celluloid, the control under the colored. The pair was moved along under the celluloid screens until the two halves appeared to be of the same color, which was increasingly darker the greater the amount of radiation. A graduated scale indicated dosage up to the full color change, which corresponded to the epilation dose, when the pastille was at half distance. Since at full distance the dose delivered is only one-fourth as great, considerably larger doses could be measured by placing the pastille on the skin instead of half way. Readings had to be made very quickly—within less than a minute after the end of the exposure—since the color faded rapidly.

Pastilles are not used at the present time, but they were of great service before the development of modern methods.

Fluorescent Standards. Since the excitation of fluorescence in certain substances was the earliest and one of the most spectacular effects observed to be produced by the roentgen rays, it was to be expected than an effort would be made to employ this phenomenon in measurement. Coutremoulins[13] (1902) proposed to compare the fluorescence produced by a beam of rays to the intensity of a standard lamp at a definite distance. Guilleminot[39] (1907) compared the luminosity due to the roentgen-ray beam to that due to a standard radioactive source. Some years later Wintz and Rump[102] (1926) described a precision instrument, the roentgen photometer, in which the fluorescent light was measured by means of a Lummer-Brodhun photometer. None of these, however, attained any widespread use.

Photographic Radiometers. Stern,[91] in New York, appears to have been the first to use a photographic method of dosage measurement; his paper was published in 1903. Subsequently others elaborated on it; the best known was probably the Kienböck Quantimeter (1904).[50,51] This consisted of a standard scale of photographic half tones, white at one end, almost black at the other, with seven intermediate grays calibrated in units based on the epilating dose. Strips of silver bromide paper enclosed in light-proof envelopes were furnished. One of these was placed on the skin in the center of the field of radiation, and removed and developed at the end of the treatment. If fractional treatments were being given, one strip could be carried through the entire series, and developed at the end, to record the total dose, while others could be used to check the daily doses. The strips, after careful development, were compared with the standard. The photographic method had the advantage of affording a permanent record of the treatment; however, it had several serious disadvantages. Like the pastilles, it has now been replaced by more accurate instruments.

Selenium Cell. The discovery that the electrical resistance of metallic selenium was changed under the action of visible light or of roentgen rays, led to attempts to employ it in the measurement of radiation

quantity. The Fürstenau intensimeter developed in 1915,[31] was the only successful commercial instrument of this type, and it was never very widely used, partly because of inherent instabilities and partly because within a few years better methods became available. It was, however, the first practical instrument by means of which it was possible to measure the output of the roentgen tube while it was in operation. The active selenium was enclosed in a light-tight cell at the end of a long cable consisting of two electric leads attached to the two ends of the metal strip. This comprised one arm of a Wheatstone bridge (an instrument for measuring electric resistance), the rest of which was enclosed in a box to which the leads were connected and which could be kept at some distance from the roentgen tube. The indicating galvanometer was also in the box, reading on a glass scale set into one side of it. The selenium cell was placed on the skin of the patient, in the center of the irradiation field and the bridge adjusted so that the galvanometer reading was zero. When the roentgen rays were turned on, the resistance of the selenium decreased, the bridge was unbalanced to a degree indicated by the galvanometer reading. Within limits, this was proportional to the intensity of the radiation. A scale was provided for reading this intensity in "I units" and conversion data were supplied for relating these to the Sabouraud and Holzknecht units.

Physical Factors of Radiation. As long as roentgen tubes and sources of high potential were subject to great individual variations, the output of radiation fluctuated from exposure to exposure, and even from minute to minute, and it was necessary to measure dosage for each treatment. After the introduction of the closed core transformer and the invention of the Coolidge tube, equipment was available which operated with remarkable steadiness. It then became possible to control dosage by controlling the physical factors. These were voltage, milliamperage, target-skin distance, filter, and time of exposure. (The size of the irradiated field, which is usually listed as a physical factor, need not be considered here.) If a radiologist decided to use a certain voltage-filter-distance-milliampere combination, he could determine experimentally the time required to produce an epilation or an erythema. Then by giving longer or shorter exposures he could administer fractions or multiples of the erythema dose. However, he could not alter any of the other factors without re-determining the standard dose.

In 1915 and 1916, Shearer[83,84] collected theoretical and experimentally determined data regarding variation in dose with variation in physical factors and established a formula which was long the sole basis for dosage determination for many therapists, particularly dermatologists. This was based on "observed" facts* that (*a*) the intensity varies directly as the milliamperage; (*b*) the intensity varies directly as the square of the voltage; (*c*) the intensity varies inversely as the square of the distance from the target to the skin. Hence the dose of radiation for any treatment varies as

$$\frac{\text{milliamperes} \times \text{kilovolts} \times \text{kilovolts} \times \text{minutes}}{\text{distance} \times \text{distance}},$$

and the result of a change in any one of these can be calculated. It must be noted that the filter does not appear in this formula; it holds for any given filter, but the basic dose must be re-determined for each one.

MacKee[61] promoted the practical use of this formula, determining basic doses for all filters customarily employed in dermatologic practice.

During this period the radiologist, who customarily worked with fairly fixed sets of factors except for time, fell into the habit of specifying his doses in terms of milliampere-minutes, the product of the milliamperes and the time of exposure. Of course the number of milliampere-minutes required to deliver an erythema dose is

* Actually (*b*) is true only over a very limited range, as has been shown by more extensive observation.

dependent on voltage, filter, and distance, and these should always have been explicitly stated. Unfortunately, in many old records this is not the case.

Ionization Methods. All the foregoing dosage measuring schemes have now been displaced by methods depending on ionization; that is, a change in electrical conductivity when matter is traversed by roentgen rays. This phenomenon was observed by Röntgen within a few weeks after his discovery of the rays. Electroscopes and electrometers, were utilized by the Curies in France, Wilson and others in England, and Geitel and others in Germany, in the first few years of study of roentgen and radium radiations. However, the possible use of these instruments in dosage measurement was not considered for some time. The first reference found in the literature is an article published in 1905 by Milton Franklin,[28] lecturer in electroradiotherapy at New York Polyclinic Hospital. After pointing out defects in photographic and pastille methods, and explaining that simple reading of meters meant little with the unstable equipment then in use, he described his electroscope. This was a metal box containing an aluminum fiber mounted on a metal post, and an electrostatic charging device. The beam of rays entered the box through a narrow aperture, and windows permitted the entrance of light and the observation of the discharge of the fiber. A scale was provided for reading varying degrees of discharge, which corresponded to varying doses of radiation.

One or two other instruments were reported in which the entire electroscope was placed in the beam of radiation, although it was recognized that this was not satisfactory. Villard,[99] in 1908, designed a combined ionization chamber and electrometer, with a scale calibrated in Holzknecht units. However, he suggested a new unit: "The unit of quantity of x-rays is that amount which liberates by ionization one electrostatic unit of charge per cubic centimeter of air at normal temperature and pressure." This is essentially the same as the roentgen which was officially adopted a number of years later; at that time, however, neither the method nor the unit received much consideration.

A few years later (1914), Szilard[92,93] approached the dosage measuring problem more critically than had anyone up to that time. He reviewed the various methods used in dosimetry, and pointed out that ionization had been most generally employed by physicists in their investigation of roentgen and radium radiations. The question had been raised of the parallelism between ionization and biological effects; he admitted it had not been answered, but added that this was also true for all the other methods. The advantages of the ionization method were listed:

1. The x-rays themselves are measured, hence the measurement is independent of all radiation factors.
2. Ionization is unaffected by any physical factors other than the radiation.
3. The radiation can be measured in absolute electrical units.

He then set forth the requirements for a satisfactory and practical instrument—requirements which still cover most of the factors to be considered:

1. The instrument must integrate the total quantity of radiation, whether this is given at a single exposure or with interruptions (i.e. no time factor).
2. The indications must be consecutive, the scale showing not only units but fractions of units.
3. The readings should be given by the motion of a needle on a scale, so as to avoid any personal error.
4. It must be possible to make the measurements in the actual place that the radiation is required, wherever that may be, whilst the scale should be easily read at some distance from the irradiated area, so as to protect the operator from injury.
5. The instrument must only be sensitive to the radiation at one definite point—the receiver—it must therefore be adequately screened from all perturbing or parasitic action of the rays.

6. The apparatus must work equally well with any installation.

A proper ionization instrument was stated to fulfill all these conditions; and he presented his, the iontoquantimeter. The ionization chamber, of 1 cubic centimeter volume, was enclosed in thick lead on all sides except the top, which was of very thin aluminum to admit the radiation. It was attached to one end of a long cable of flexible rubber, carrying an embedded wire connected to the center electrode and shielded with a flexible metal tube. This wire led to the electrometer, with a needle reading directly on the scale.

Szilard proposed a new unit instead of Villard's. He felt that the fundamental significance of the ion should be recognized, and his unit was "the amount of radioactive energy necessary to set free a single ion in air under normal conditions of temperature and pressure." Of course this was much too small for practical use, so the practical unit was to be the mega-mega-ion or 10^{12} ions; this is equivalent to 340 electrostatic units.

Christen[11] (1914) accepted Szilard's unit and instrument. However, he called attention to the fact that the dose is not the quantity of radiation impinging on a surface, but the energy absorbed. He therefore proposed as the unit of dose "10^{12} ions absorbed by one cubic centimeter of dry air at 15° C. and at normal atmospheric pressure," and suggested that it be called a szilard. He then suggested that it might be even better to calculate in ergs the amount of energy whichwould be required to set free 10^{12} ions. The dose would then be expressed in ergs per cubic centimeter.

Thus, by 1914 the units accepted at the present time had been proposed. However, a considerable amount of time was to elapse and much research to be carried out before they were formally accepted.

Both Szilard and Christen encountered practical difficulties with their ionization chambers. The reasons for this were complicated—partly due to neglect of such precautions as the employment of saturation potential on the chamber, and partly due to ignoring the effect of scattered and secondary radiations from the chamber itself or from surrounding objects. Physicists had long been aware of the significance of these factors in ionization measurements, but their importance was not realized in practical dosimetry. Duane[19] called them to attention repeatedly, after 1914, pointing out particularly that ionization chambers used for standardization should be of the "open air" type. That is, the beam of radiation should enter and leave the chamber by diaphragms and the ionization in the air should be due only to the primary beam and not to any secondary or scattered rays from any metal or other solid parts of the apparatus. He reworded Villard's definition to state that "the electrostatic unit is that intensity of radiation which produces under saturation conditions one electrostatic unit of current per cubic centimeter of air under normal pressure and temperature" and designated it as E.

In 1918 Krönig and Friedrich[55] published their comprehensive study on roentgen-ray measurements. They used the unit defined by Villard, calling it *e*. In 1921 Solomon[87] proposed his unit, R (Röntgen) defined as "the intensity of a roentgen radiation producing the same ionization per second as one gram of radium placed 2 cm. from the ionization chamber and filtered with 0.5 mm. of platinum."

By this time it had become apparent that some form of ionization unit would be preferable to any other method of measurement then available. It was also realized that standardizing the output of a roentgen tube was not the only thing necessary in describing the dose of radiation received by the patient, but that the physical factors of the radiation, the size of the patient, the position of the tumor mass, and other conditions had to be considered. Hence research proceeded along two lines, standardization and clinical dosage. With regard first to the matter of standardization, two interlocking problems had to be settled—the best choice and definition of

the unit, and the development of measuring methods to insure that the unit was correctly realized and employed. Studies were carried out in physical-radiological laboratories in various parts of the world, particularly in Germany, France, England, Sweden, and the United States, and the results presented first at national and then at international radiological meetings. Space does not permit a detailed history of this development, but the main points should be mentioned.

The Unit of Quantity of Radiation. In Germany the unit first proposed by Villard[99] was adopted. Behnken[4] reworded the definition as follows: "The absolute unit of roentgen-ray dosage is defined as that amount of radiation which, in one cubic centimeter of air at 18° C. temperature and 760 mm. mercury pressure, on full utilization of the secondary electrons arising in the air, and with avoidance of wall effects, produces such a degree of conductivity that the quantity of electricity measured under saturation conditions amounts to one electrostatic unit. The unit of dose is called one Roentgen and is indicated by R." Both at the Reichsanstalt and at various university laboratories, ionization chambers and measuring instruments were developed to meet the conditions laid down by the definition.[55,56] The German Roentgen Ray Society adopted the unit.

In France, the Solomon unit, R, was promptly accepted. This differed considerably from those of the other countries both in definition and in the method of measurement. Whereas, as will be seen, in all other countries the standard instrument was developed as a large open air ionization chamber, so that the measurements depended only on ionization in air, Solomon's instrument was a small thimble chamber of a particular construction.[88] The results of these differences contributed to the long lasting confusion over dosage specifications and controversy regarding the acceptance of an international unit.

In England studies were carried out at the National Physical Laboratory, mainly under the direction of Kaye and Laby, but little appears to have been published from there prior to 1928.

In Sweden, Sievert and his associates at the Radiumhemmet were the principal workers. Their first interest was in the measurement of radium radiations, but as they began to employ roentgen rays extensively they also entered that field.

In the United States, Duane, as mentioned earlier, had been one of the first to point out the importance of the open air chamber. He continued to study the problem at Harvard University, while the physics departments of the Memorial Hospital and the Cleveland Clinic, and somewhat later the Bureau of Standards, also engaged in extensive research.

International Standards of Quantity. The First International Congress of Radiology met in London in 1925, and the matter of an international dosage unit was one of the principal topics. The German and French delegations had definite, but very different, recommendations; the others felt that the time was not yet ripe for decision, and the question was deferred until the Second International Congress of Radiology at Stockholm in 1928. In the meantime improvements were made on all equipment, and many more data accumulated.[6,20,33,88 and others]

At the Second International Congress, a number of papers were presented on the question, notably one by Failla[24] setting forth in detail what must be accomplished by a standard open air chamber, and how this might be achieved. The International X-ray Unit Committee, consisting of twenty-four members from fifteen countries, submitted provisional recommendations which were adopted by the Congress.[91] The unit was specified as "the quantity of X-radiation which when the secondary electrons are fully utilized and the wall effect of the chamber is avoided, produces in one cubic centimeter of atmospheric air at 0° C. and 76 cm. mercury pressure, such a degree on conductivity that one electrostatic unit of charge is measured at

saturation current." The unit was to be called the "roentgen" and designated by r.

This definition was left unchanged at the Third International Congress of Radiology in Paris in 1931. At the Fourth International Congress of Radiology in Switzerland in 1934, the question was raised of broadening the definition so that the unit could also apply to gamma rays. Finally, at the Fifth International Congress of Radiology, in Chicago in 1937, the International Committee for Radiological Units, of twenty-three members, representing twelve countries, adopted a definition which was again to be regarded as provisional until the next congress, and which is the one used at present:[77]

1. The International Unit of *quantity* or *dose* of x-rays or gamma rays shall be called the "roentgen" and shall be designated by the symbol "r".

2. The roentgen shall be the quantity of x- or gamma-radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying 1 e.s.u. of quantity of electricity of either sign.

Standard Ionization Chambers. As soon as an international definition was first established, various laboratories in the different countries developed standard instruments, against which secondary standards could be calibrated. Inter-laboratory and international comparison of these standards was highly desirable. However, the standard chambers were heavy, and difficult to transport, and it was necessary to develop small secondary chambers, which could be calibrated against the national standards and carried abroad for comparison with other instruments. Glasser and Portmann[33] developed such small chambers and by means of them compared several standard chambers in this country, finding agreement to ± 4 per cent. Several French instruments calibrated by the Solomon standard and sent to the United States were found to agree among themselves within ± 5 per cent, and to give a ratio of 1 roentgen equivalent to 2.1 Solomon R. Seven German instruments, however, only agreed to within ± 13.5 per cent, and showed a difference of 50 per cent between the German and the American roentgens, the former being larger. This discrepancy was intolerable and Behnken constructed two chambers with special care, brought one himself to America and sent the other by Jäger by a different route.[5] With these instruments they found only 4 per cent instead of 50 per cent difference from Glasser and Portmann's standard. They also checked the Solomon unit and found a ratio of 2.26 R to 1 r. A considerable number of other comparisons through secondary standards were made in various European countries.

In 1930 Taylor,[91] at the United States Bureau of Standards, devised a guarded field standard ionization chamber that made it possible to construct a standard instrument in portable size. This he took to Europe and was thus able to make direct comparisons in the standards laboratories of England, Germany, and France.[95] Careful comparisons under standardization conditions showed less than 1 per cent discrepancy among the four standards, when the Solomon ratio was taken as 2.29 R = 1 r. As a consequence of this study, Solomon adopted the guarded field chamber instead of the closed thimble chamber. From the physical point of view, the roentgen is now an accurately established unit.

Clinical Dosimetry. While all this research was being carried out on the standard dosage unit and measuring device, dosimetry was also developing along other lines. Fundamentally, the need for dosage determination is in relation to the patient—how much radiation is administered and what can be expected from it. The earliest devices were designed to show when an erythema or epilation dose had been administered, and for many years some form of erythema dose was accepted as the unit. The literature contains numerous articles relating the erythema dose to Holzknecht, Kienböck, or other units, for different voltages and methods of admin-

istering the radiation. After standardization of machines by roentgen output as measured in air chambers became common, radiologists still desired to know how many roentgens corresponded to an erythema dose and the latter continued to be the clinical unit for some time.

In the earliest attempts at dosage measurement, no distinction was made between the dose in air, that on the surface of the patient's body, or that actually received by the tissues supposed to be undergoing treatment. However, it was promptly realized that absorption of radiation in superficial tissues reduced the amount arriving deep within the body, and efforts were made to measure this reduction. Since at this stage the influence of target-skin distance and the contributions of scattered radiation to the tissue dose were not recognized, it seemed that any method of measuring the absorption would give the desired information. Thus, with any of the early dosimeters a sheet of material could be interposed between the tube and the indicator and the depth dose measured.[3,50,52,54] Furthermore, it was assumed, after some preliminary tests, that absorption in 1 mm. of aluminum was equivalent to that in 1 cm. of tissue or water, and depth doses were considered on that basis.

As soon as absorption measurements began to be made, it became evident that a layer of material in the path of the beam, while it decreased the intensity, increased the penetrating power, and so *filtration* began to be used.[58,68,69,78] Actually Röntgen had foreshadowed this in his third paper, in March, 1897, in which he said, "If we imagine a substance divided into layers of equal thickness, placed perpendicular to parallel rays, each of these layers is more transparent for the transmitted rays than the one before it. . . . The rays emitted by a discharge-apparatus consist of a mixture of rays which are absorbed in different degrees and which have different intensities.[32] . . . "

The first mention of effect of *target-skin distance* found in the literature is by Williams[101] in 1903. Dessauer[14] (1912) was strongly impressed with the necessity of having homogeneous irradiation throughout the part of the body undergoing treatment, and pointed out that both distance and filtration could contribute to this condition.

In pursuance of his search for homogeneous irradiation, Dessauer[15] constructed a "phantom" of strips of animal tissue 1 cm. thick. Between these he placed Kienböck strips, which were all developed simultaneously, thus giving a "depth dose" actually measured instead of calculated. He found that this dose was greater than would be expected on a basis of absorption and inverse square law, and correctly attributed the increase to scattered and secondary radiation arising within the phantom. Barkla[1,2] and others had demonstrated the existence of these radiations earlier, but their significance in therapy had not been appreciated.

Since no way was known of calculating the contribution of the secondary radiation to the depth dose, more satisfactory phantom measurements, simulating actual treatment conditions, were desirable, and in 1918 Krönig and Friedrich[55] published their extensive and painstaking studies. They used a small ionization chamber on the end of a flexible cable well shielded from radiation effects, and as a phantom a tank of water 35 cm. in diameter and 25 cm. deep. When they tested different ionization chambers it became evident that the material of which the chambers were constructed was very important, as would be expected because of secondary radiations from the walls. The character and amount of these secondary rays not only depended on the nature of the wall material, but on the voltage and filter used in producing the roentgen-ray beam. For this reason the chambers of such instruments as Szilard's[92] with walls of heavy metal, were not suitable for dosage measurements. Krönig and Friedrich compared chambers of thick and thin alumi-

num, carbon, and horn, calibrating each against their open air standard chamber. They found that the horn chamber gave readings in the same ratio to those of the standard over a much wider range than any of the others, and therefore used it for their final depth dose measurements. They also compared these chambers with other types of dosimeter—Kienböck, Fürstenau, Sabouraud-Noiré.

Krönig and Friedrich then made careful and detailed measurements of the radiation on the surface and at various depths in the phantom, for a range of fields and filters. By covering the region of the primary beam, they actually measured the secondary radiation. And they studied the distribution of the radiation throughout the field, demonstrating a slight decrease toward the edge of the geometrical beam and an abrupt drop outside it. This work may be considered the basis of modern determination of tissue dosage. Many investigators since then have carried out much more extensive studies, realizing that actual measurement was necessary for all practical sets of physical factors.[9,16,26,59, and others] Dessauer and Vierheller[16] developed charts showing the distribution of radiation in vertical and horizontal planes in beams of various sizes. The term *isodose charts*, coined by Friedrich and Glasser with regard to distribution of radiation around radium sources[30] is now generally applied to such distribution charts in the vertical plane. The use of such charts in actual size in conjunction with life-sized anatomical cross-section diagrams for accurate determination of dose at any specified point within the body, was advocated by Failla,[23] Weatherwax and his associates,[100] and others.

Glasser and his associates were particularly concerned with constructing a small thimble ionization chamber whose walls should have the same secondary radiation as air, or be "air-wall."[29] Such a chamber should give readings parallel to the standard open air chamber over a very wide range of quality. Very satisfactory instruments of this type have now been developed.[36] Sievert, Glasser, and others developed small air-wall chambers in the form of condensers which could be separated completely from the measuring electrometer during exposure to the radiation.[34,62,86]

One other development deserves mention, although it has not yet led to any practical result. Since the effective dose of radiation is the energy *absorbed* by the tissues, it would be highly desirable actually to determine this, as pointed out by Failla and others.[22] This has not yet proved practical. It is accepted that ionization produced in tissue is proportional to energy absorption, and that ionization per gram of air is for practical purposes equivalent to that per gram of tissue, *under identical circumstances of irradiation*. Hence ionization in air has generally been adopted as a satisfactory method of determining dosage. However, mention should be made of attempts to fill the ionization chamber with organic liquid and thus more closely simulate conditions in the tissue.[89,96] Up to the present time, such chambers have not proved of practical value. More recently, as will be discussed later, Mayneord has proposed a method of calculating energy absorption from isodose curves and thereby expressing total body dose.

At this stage in the development of dosimetry it was possible by means of standard open air chambers to measure accurately in roentgens the output of radiation in air, and by means of air-wall thimbles, the ratio of radiation delivered anywhere within the body to that falling on the surface. But the relation of the surface dose to the air dose was still not accurately established. The air wall thimble could measure roentgens correctly in air, after it had been calibrated against a standard, for a wide range of radiation qualities, but it was not certain whether this range was sufficient to account for the very soft portion of the secondary radiation at the surface of the body, so that doses delivered in the tissues could be expressed

in roentgens. There were also other possible errors to be considered. The development of the extrapolation ionization chamber by Failla made possible the absolute measurement of tissue dose, both at the surface and within the depths of the phantom.[25,75] It was then found that, over a wide range of quality of primary beam, suitably constructed thimble chambers could be employed to measure surface and depth doses. As the voltage range employed in therapy has extended into both higher and lower regions, special standard and air-wall chambers have been devised to meet the new conditions.[57,70,72,73]

Thus, the problem was settled of reconciling measurement in air in terms of roentgens and in tissue in terms of fractions of an erythema dose, or other biological unit. At the present time, dosage is specified in terms of roentgens delivered at the point where the radiation is utilized.

In practice, the output of the roentgen-ray tube is measured by means of an air-wall thimble chamber which has itself been calibrated against an open air standard chamber. With modern equipment the output is usually very constant, so that it need be measured only at intervals. Knowing the roentgens per minute in air, or the total roentgens delivered in air, the radiologist refers to published charts or tables to determine the roentgens per minute or total roentgens on the surface of the body or at any desired depth.[35,64, and others] Or he may decide what dose he wishes to administer to the tumor itself, and by means of the same tables determine the necessary exposure times.

A number of dosimeters are on the market in Europe and America which satisfactorily measure the tube output in air. Most of the European instruments have the air-wall thimble chamber permanently attached to the current measuring device through a shielded cable. The one in general use in the United States is of the condenser type. Instruments are also available for measuring the actual dose on the skin of the patient during treatment. These have not met with general acceptance. They are expensive, complicated, and, in view of the satisfactory dosage tables available, not particularly desirable.

At this point mention should perhaps be made of the *monitor* ionization chambers mounted in the roentgen-ray treatment cone and reading continuously while the machine is in operation. These are not dosimeters in any sense of the word, but simply, as their name implies, indicators that the apparatus is functioning correctly. When the roentgen-ray output is calibrated with a proper air-wall chamber, the reading of the monitor is noted, and as long as it continues to give identical readings and *voltage and filter remain unchanged*, the output is as measured. Since these monitors usually contain sheets of aluminum through which the beam passes, the ionization is largely due to secondary radiation. Any small change in quality of primary beam results in an unknown change in secondary radiation. Therefore, it is not practicable to calibrate such an instrument and use it as a measure of dosage.

The Specification of Quality. Up to the present point, little has been said about the measurement of *quality* of radiation. Röntgen observed that the greater the length of the parallel spark gap, the more penetrating the x-ray beam.[32] He studied the quality by observing the penetration through a "platinum-aluminum window," a piece of platinum foil and a ladder of aluminum. Either roentgenoscopically or photographically he determined the thickness of aluminum having the same transparency as the platinum, and found that it increased as the rays were filtered.

The Benoist penetrometer (1902) was based on the same principle.[7] It consisted of a silver disk surrounded by a circular aluminum ladder. The aluminum steps were numbered, and the one which matched the silver disk represented the quality in B units. At that time it was believed that silver was "achromatic" with respect to roentgen rays; that is, that all qualities

penetrated it equally, whereas aluminum and many other substances were "chromatic," so that the differential was a true measure. Although this was disproved, the method was still more widely used than any other for a long period.

Villard[98] in 1908 devised an ionization chamber to give an instantaneous reading of quality. This was really a double chamber with the common wall forming a filter. The reading of the electrometer gave the ratio of the unfiltered to the filtered beam; it was calibrated according to the Benoist scale.

In 1912, Christen introduced the concept of *half-value layer* as a measure of quality.[10] He felt that tissue or water should be used, but since this was impractical he substituted bakelite. His apparatus contained a sheet of heavy metal, covered with regularly spaced small holes of such dimensions that the sum of the areas of the holes was just half the area of the sheet. Beside this was a ladder of bakelite. A fluorescent screen was mounted at such a distance from the metal and bakelite that roentgen rays passing through the holes did not show the individual perforations, but produced a uniform illumination. Since half the area of the plate was open, the beam passing through it was just half of the original quantity. The thickness of bakelite which transmitted radiation illuminating the fluorescent screen to the same degree as the perforated plate was the half-value layer. Christen also called attention to the fact that in inhomogeneous radiation the second half-value layer was considerably greater than the first, whereas in truly homogeneous radiation they were equal. Hence the ratio of second half-value layer to first furnished a measure of the homogeneity of the beam.

Szilard[92] considered the methods of Villard and of Christen the "only irreproachable ones," but proposed that the *absorption coefficient* in air would have more meaning. Since, however, he determined this by finding the half-value layer in water and multiplying by a constant, he really offered nothing new.

Various other devices, such as the sklerometer of Klingelfuss,[53] which depended on special electric circuits in the secondary of the roentgen-ray generator, never attained widespread use.

In the United States the specification of quality by voltage or *equivalent spark gap* was most commonly employed, during early years of therapy.[85] The spark gap gives a measure of peak voltage, which determines the minimum wavelength in the beam of roentgen rays. This, however, is a very small part of the entire beam, and the length of the spark gap gives no information about the radiation comprising the remainder. It is therefore not a satisfactory method of quality determinaation. Furthermore, with the development of "constant potential" installations with large condensers in the secondary circuit, and with other modern improvements, direct application of spark gaps is often impracticable.

The *spectrometry* of roentgen rays led to a better understanding of the meaning of quality, but the complete spectrum was obviously not practical for a radiological specification. It was shown, however, that there was a mathematical relation between peak voltage exciting the roentgen-ray tube, and minimum wavelength in the spectrum. Seemann[82] (1924) developed a simple and rugged spectrometer for determination of minimum wavelength, which enjoyed a certain popularity. Since specification of minimum wavelength is subject to the same criticism as that of spark gap, the method is not satisfactory.

Instead of the minimum wavelength, some sort of average value which should more nearly describe the entire spectrum, seemed desirable, and Duane proposed the *effective wavelength*.[18] This is the wavelength of the monochromatic roentgen ray that has the same absorption in 1 mm. of copper as the whole beam under consideration. Other suggestions were an *average wave-*

length, obtained from an average absorption coefficient, or the *average absorption coefficient* itself, in a specified material. A metal, usually copper, was advocated instead of the air or water used by Szilard. Christen's idea of half-value layer was also favored, but again a metal was preferred to water. Holthusen and Gollwitzer[45] used copper, while Meyer and Braestrup[66] selected aluminum. Mayneord and Roberts,[65] after a critical discussion of methods of quality specifications, concluded that the simple half-value layer was not satisfactory, but recommended that if it was to be used, tin was the best medium. No one of these methods gives a rigid specification of quality; beams "equivalent" by one method are not necessarily so by another.[71] Any one of them could, however, be used within certain limits if general agreement on these limits could be obtained.

A different approach to the subject was that of Taylor and Singer[97] (1934) who made absorption curves in aluminum and in copper for roentgen rays produced at definite constant potentials. A similar absorption curve taken for any beam could be compared with the standard series and its constant potential equivalent determined.

International Standards of Quality. At the Second International Congress of Radiology, the matter of quality specification was considered, and left in a rather indefinite state. Voltage, filter, and general character of high tension apparatus were to be stated, and either half-value layer in "a suitable material" or effective wavelength. At the Third International Congress of Radiology, it was stipulated that in addition to tube voltage, the half-value layer should be specified; in copper if it exceeded 0.1 mm., and in aluminum for less penetrating rays. The Units Committee for the Fourth International Congress recommended that for exact physical measurements, complete absorption curves in copper or aluminum were required but that for practical purposes the quality might be expressed by the first and second half-value layers of the same materials. The International Committee for Radiological Units of the Fifth International Congress of Radiology specified that:

> For most medical purposes it is sufficient to express the quality of the x-radiation by the half value layer in a suitable material: Up to 20 kv. (peak) cellophane or cellone; 20–120 kv. (peak) aluminum; 120–140 kv. (peak) copper; 400 kv. up (peak) tin. For a more definite specification of the quality of the radiation the complete absorption curve in the same material is preferable.

It is recognized that the quality of the radiation changes as the beam passes into the body, becoming steadily less penetrating. Some attempts have been made to measure the quality where the radiation is actually absorbed, with the idea that this might have more significance in therapy than the quality emitted by the tube. Quimby and McNattin[76] made actual absorption curves within the depths of a paraffin phantom, by surrounding their ionization chamber with concentric shells of copper. In this way the half-value layer could be determined at the site of utilization of the rays; for filtered 200 kv. roentgen rays of half-value layer 1.14 mm. copper in air, the half-value layer at 10 cm. depth was 0.7 mm. Clarkson and Mayneord[12] carried out experiments using a double ionization chamber, one section made entirely of carbon, the other incorporating a copper absorber in the walls. However, the problem is technically difficult, and while of theoretical interest, has not been demonstrated to be practically important.

Any discussion of dosimetry in radiology would be incomplete without some mention of its relation to biological reactions. The early literature contains many references to the relation between the various proposed units and the erythema dose or skin unit dose. Numerous workers have made extensive studies with biological test

objects in comparison to ionization chambers in efforts to arrive at true biological dosimetry. Thus, to mention but a few, Jüngling,[48] and Glocker and his associates[37] used bean roots, Holthusen,[44] *Ascaris* eggs, Wood[103] and Packard,[67] *Drosophila* eggs, Henshaw,[41,43] various seeds and eggs.

Work with living organisms inevitably led to the realization that a knowledge of the effect of the *rate of administration* of the radiation was an essential part of biological dosimetry. This had been pointed out by Christen[11] in 1914. Its importance when treatment is given by protracted or fractionated techniques is very great, and at the present time little definite information is available. The studies on recovery as related to erythema production by Reisner[79] and by Quimby and MacComb,[60,74] of Henshaw,[42] on time of cleavage of marine invertebrate eggs, and of others,[38] have only furnished an introduction to the matter. The time factor is at present one of the outstanding problems in dosage determination.

The other is the question of "body dose" or total amount of energy absorbed by the patient. The number of roentgens delivered to a deep-seated tumor with any given set of physical factors may be twice as great for a large field as a small one, but the actual amount of energy absorbed by the patient's body may be many times as great for the large field. The importance of total body dose was early pointed out by Christen.[11] Stenstrom[90] again called attention to it in 1924. In recent years, intensive study has been done, particularly by the British group of radiation physicists.[21,62,63] Mayneord has proposed as the unit the gram-roentgen, the energy conversion when one roentgen is delivered to one gram of air, which is approximately 85 ergs. Since this is very small, his practical unit is one million times as great, the megagram-roentgen, which is equivalent to about 2 gram calories.

SUMMARY

The purpose of this paper has been to present a historical survey of dosimetry in roentgen therapy from its beginnings to the present time. It is fitting, at this fiftieth anniversary of Röntgen's discovery, to review critically what has been accomplished and to look ahead at what needs to be done. The measurement of quantity of roentgen radiation in air is definitely settled. In clinical dosimetry, theory is ahead of practice, and there are still unsolved problems. However, the available information, properly used, puts radiation therapy on a reasonably exact basis, as far as its physical aspects are concerned. The question of quality measurement is not settled, but present standards permit satisfactory exchange of information.

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UTILIZATION OF ANTIBODY FOR THE LOCALIZATION OF METALS AND DYES IN THE TISSUES

PRELIMINARY REPORT

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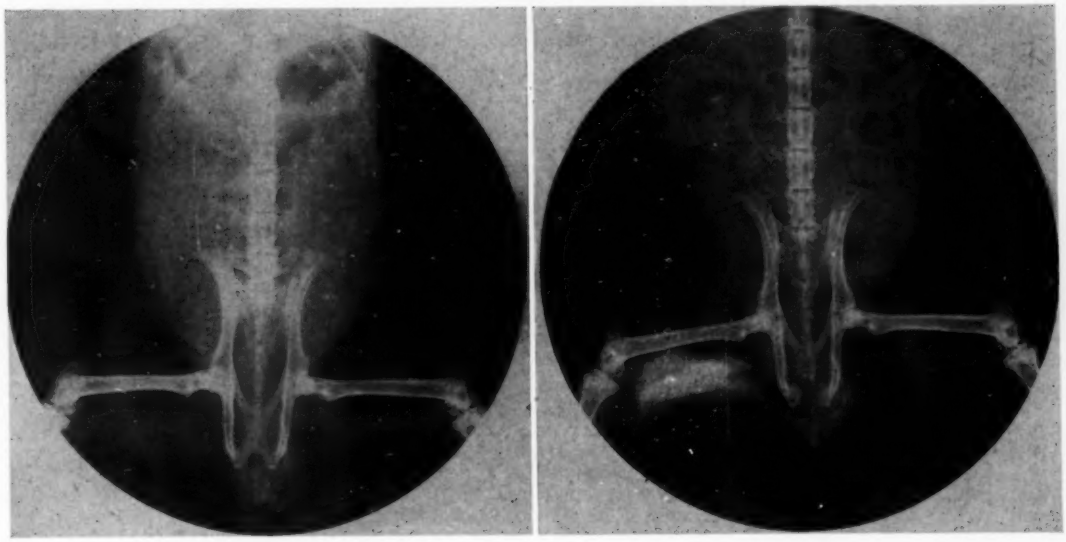
THE antigen-antibody reaction and the properties of antibody under various conditions have been studied extensively. The outstanding characteristic of antibody is that when it unites with an antigen it does so specifically. In this paper we present experimental evidence that this specificity can be utilized to transport metals and dyes which have been combined with antibody, to predetermined sites in the tissues. Details of the method used to form the metal or dye antibody combinations will be described in another publication.

EXPERIMENTAL

Experiment No. 1. Localization of Heavy Metal by Means of Antibody (Pneumococcus Type I). A control roentgenogram (Fig. 1*A*) was made of the pelvis and hind legs of a 450 gram guinea pig after the right thigh of the animal was infiltrated with 10 milligrams of pneumococcus polysaccharide, Type I, suspended in 0.5 cc. of normal saline, and the left thigh was infiltrated in the same way with 10 milligrams pneumococcus polysaccharide, Type II. The left femoral vein was then exposed and 2.0 cc. of pneumococcus antibody, Type I, combined with approximately 60 milligrams of uranium was injected intravenously. The animal died about twenty minutes after the injection of this material. A roentgenogram was then made (Fig. 1*B*). It showed a striking deposition of metal in the soft tissues of the right thigh at the site where the muscle was infiltrated with pneumococcus polysaccharide, Type I. None appeared on the opposite side where the Type II pneumococcus polysaccharide was injected.

Experiment No. 2. Localization of a Heavy Metal by Means of Antibody (Pneumococcus Type II). This experiment was similar to No. 1 except that pneumococcus antibody, Type II, containing approximately 60 milligrams of uranium was substituted for pneumococcus antibody, Type I. A preliminary roentgenogram of the pelvis and hind legs of the guinea pig was made (Fig. 2*A*) after the right thigh of this animal was infiltrated with 4.0 milligrams of pneumococcus polysaccharide, Type I, and the left thigh was infiltrated with 4.0 milligrams of pneumococcus polysaccharide, Type II, suspended in 0.5 cc. of normal saline. Two cubic centimeters of pneumococcus antibody, Type II, combined with approximately 60 milligrams of uranium was injected into the right femoral vein. The animal died in about twenty minutes. A roentgenogram (Fig. 2*B*) disclosed a deposition of uranium in the left thigh at the site where the muscle had been infiltrated with pneumococcus polysaccharide, Type II. None appeared on the opposite side where Type I pneumococcus polysaccharide was injected.

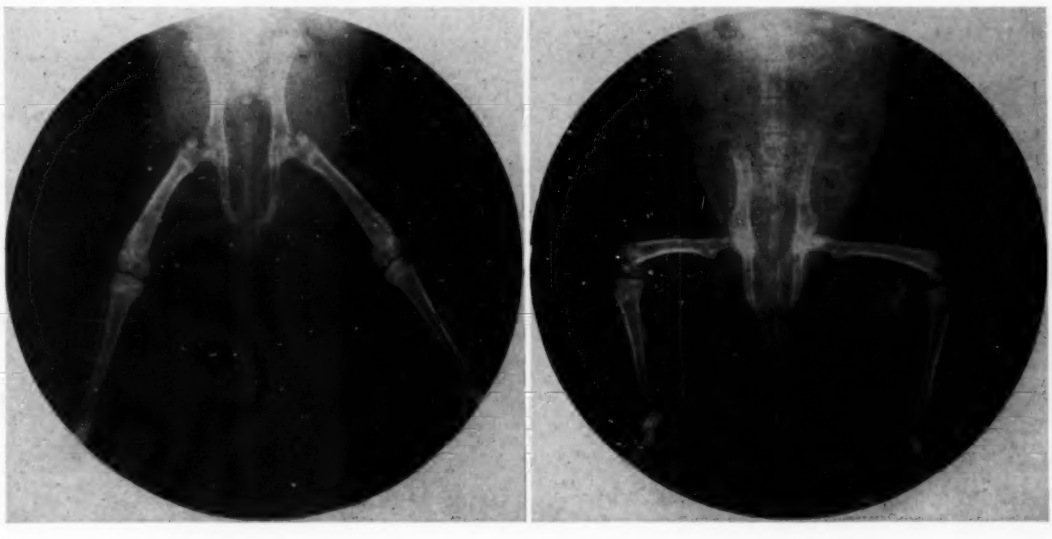
Experiment No. 3. Localization of Dye by Means of Antibody. Malachite green was combined with purified pneumococcus antibody, Type II, to form an antibody dye combination. A guinea pig weighing 300 grams was used as a control. Two cubic centimeters of pneumococcus antibody, Type II, combined with the dye was injected into the femoral vein. The left lung was then infiltrated through the chest wall with 10 milligrams of pneumococcus polysaccharide, Type I. The animal was destroyed in about ten minutes. Examination of the lungs disclosed no discoloration other than small hemorrhagic areas caused by the injection needle. Microscopically, only traces of the dye were seen in the pulmonary capillaries. The experimental guinea pig weighed about 300 grams. As in the control experiment 2.0 cc. of pneumococcus antibody, Type II, combined with the dye was injected into the femoral vein. Pneumococcus polysaccharide, Type II, was then injected through the chest wall into the left lung. The animal died in about ten minutes. Examination of the lungs showed a gross greenish discoloration on the left side. A smaller amount of discoloration was also seen in the right lung. Microscopically, large aggregates of colored precipitate were seen in the vessels occluding many of the capillaries.



A B

FIG. 1*A*. Control roentgenogram of pelvis and hind legs of a guinea pig made after infiltration of right thigh with pneumococcus polysaccharide, Type I, and left thigh with pneumococcus polysaccharide, Type II.

FIG. 1*B*. Roentgenogram of pelvis and hind legs of a guinea pig following the intravenous injection of pneumococcus antibody, Type I, combined with uranium. This shows a deposition of metal in the soft tissues of the right thigh at the site of the injection of specific antigen pneumococcus polysaccharide, Type I. None appeared in the left thigh where the Type II pneumococcus polysaccharide was injected.



A B

FIG. 2*A*. Control roentgenogram of pelvis and hind legs of a guinea pig made after infiltration of right thigh with pneumococcus polysaccharide, Type I, and left thigh with pneumococcus polysaccharide, Type II.

FIG. 2*B*. Roentgenogram of pelvis and hind legs of guinea pig following the intravenous injection of pneumococcus antibody, Type II, combined with uranium. This shows a deposition of metal in the soft tissues of the left thigh at the site of the injection of specific antigen pneumococcus polysaccharide, Type II. None appeared in the right thigh where the Type I pneumococcus polysaccharide was injected.

COMMENT

These experiments were repeated a number of times with similar results. The deposition of dye in the lung and metal in the soft tissues at the sites of specific antigen was unmistakable and took place within a few minutes after injection. It can be presumed, therefore, that the metal or dye remained firmly bound to antibody in the blood stream and that the specificity of antibody had not been materially altered by the combination. In view of the complex nature of the antibody-antigen reaction, the stability of the metal and dye antibody combinations is striking.

Purified pneumococcus antibody, uranium and malachite green were used in these antigen-antibody reactions. However, similar combinations can be made with other materials. We have combined other antibody and metals in the same way without materially altering their immunological specificity. Examples of this, details of which will be reported later, were combinations of radium F (polonium) with antibody against lymphocytoma, adenocarcinoma of the breast, and pneumococcus antibody, Type I and Type II. These experiments suggest a procedure whereby uniform radiation can be applied selectively to certain tissues.

SUMMARY

1. Experimental evidence has been presented to show that under certain conditions purified antibody can be combined with metals and dyes without altering its essential immunologic specificity.

2. Utilization of antibody for the localization of metals and dye in the soft tissues of animals has been demonstrated.

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SALIENT FACTORS IN THE TREATMENT OF HODGKIN'S DISEASE AND LYMPHOSARCOMA WITH ROENTGEN RAYS

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HISTORICAL CONSIDERATIONS

WHEN, late in December, 1895, Röntgen announced his discovery of the rays which, because he did not know their character, he chose to call "x-rays," this announcement made a tremendous sensation throughout the world. Perhaps the best account of the discovery was written by H. J. W. Dam and was published in the April, 1896, number of *McClure's Magazine* which, at that time, was one of the outstanding periodicals of this country. Within a few months, professors of physics and many others began to produce these rays by means of Ruhmkorff induction coils and Crookes tubes, and the new rays were soon being used to examine fractures and dislocations of bones, to record the situation of foreign bodies, and also to determine whether or not the rays might have a favorable influence on certain pathologic processes.

As early as 1896, an interesting example of the favorable effect of the rays was reported by Despeignes in *Lyon médical* (France). This was the case of a man, aged fifty-two, whose health had been deteriorating for some time and who was thought to be afflicted with cancer of the stomach. After various other forms of treatment had failed to influence the patient's condition, the idea of trying roentgen rays was considered. Beginning on July 4, 1896, two exposures, each of half an hour, were given daily for eight days to a single abdominal field. To the amazement and delight of all concerned, this treatment was followed by rapid relief from pain, and the size of the tumor diminished progressively. However, the patient's condition continued to improve for only a short time, when it again deteriorated, and he died on July 23, 1896. A point of great interest was that the abdominal tumor had continued to diminish until, at the time of his death, it could no longer be felt. Because, after the exposures to roentgen rays, the patient had been given injections of an "artificial serum" (Dr. Cheron's formula), Despeignes assumed that perhaps these injections had been responsible for the abatement of the pain, but he could not thus account for the reduction in size of the tumor, and he was greatly puzzled.

A review of this early case report makes it seem more than likely that, considering the physical quality of the rays generated by the apparatus available at that time, or even without considering this factor, the patient could not have suffered from carcinoma of the stomach. An epithelial tumor could not have been influenced so rapidly or so much by treatment of this kind. The abdominal neoplasm—assuming that it was a neoplasm—must have been exceptionally sensitive to roentgen rays. At that time the comparative sensitiveness of different kinds of cells to roentgen rays was not known, but our present knowledge, which is based on a large body of experimental evidence and on extended clinical observation, makes it almost certain that, in view of the history of the patient's illness, he must have been suffering from a form of lymphoblastoma (Hodgkin's disease or lymphosarcoma) of the retroabdominal (para-aortic) lymph nodes, with or without secondary involvement of the stomach. Only a condition such as this could have been affected so rapidly and so favorably by the rays. But, from the history of the case and from the large size

of the tumor, it is obvious that the malignant process had reached an advanced stage, when treatment of any kind could not be expected to stay its course for more than a short time.

GENERAL CONSIDERATIONS

The tremendous and widespread influence of habit is often astonishing. Most of us are aware of this influence on physical action or behavior, and we know how difficult it often is to break some of these habits. What is not so generally recognized is the influence of habit on thinking, and it is precisely because of our failure to recognize this influence that habits of thought, of which, as often as not, we are not even aware, are so difficult to break.

For many years—and it is more true today than ever before—it has become a habit or fashion to treat every kind of malignant tumor essentially by the same method. Thus, in general, carcinomas or epitheliomas, fibrosarcomas, chondrosarcomas, lymphoblastomas and so forth, are treated with rays generated at 200, 400, 600, or even 1,000 kv., and filtered through 0.5, 0.75, 1.0, 2.0 or more millimeters of copper or zinc, but sometimes part of the filter may consist of a certain thickness of tin, and the treatment usually is given by the fractional method or by some modification of it. Commonly the aim is to deliver to the tumor or tumors the largest total dose which can be given without producing irreparable damage to the normal tissues.

Why has this basic method been so widely adopted? After all, methods of treatment do not fall ready-made from heaven but are based on certain lines of thinking. The principal factors are: (1) the well founded idea that rays of different wave lengths act on cells and tissues in the same way, although the degree of their action varies with the quantity of rays received by the cells; (2) the concept of "depth dose," according to which the greater the quantity of rays which penetrates the body to a depth of, let us say, 10 cm., the greater must be the action of the rays on the tumor; (3) the more penetrating the rays (the greater the depth dose), the less danger there is of injuring the skin; (4) the experiments of Regaud and his co-workers, which had shown that, when a given area is exposed to a small dose daily for a long time, a much larger total dose can be given without serious injury, and (5) the experiments of Wood and Prime, which had proved that it takes from five to eight times an erythema dose completely to arrest the growth of an epithelioma or carcinoma.

There is no doubt that the main reason why the first two of the factors which I have mentioned have had, and still have, such a widespread influence on roentgen treatment has been the teaching of physicists who have justly stressed these points. The third factor has come from the universal desire, on the part of radiologists, to avoid serious injury to the skin and the lawsuits which sometimes follow.

Physics is an important phase of therapeutic radiology but, as I shall attempt to bring out later, treatment based entirely on physical factors may not always yield the most favorable results. Cellular biology also is an important phase of therapeutic radiology, but too often it does not receive as much attention as it deserves. It is certain that, when a radiologist allows himself to be so completely submerged by physical considerations that he overlooks the biologic factors, the results which he obtains may not be as good as they might be.

No one can question the experimental results obtained by Regaud and his collaborators[9–21] or those obtained by Wood and Prime. Long application of these results by many radiologists throughout the world have fully confirmed their validity as far as epithelial neoplasms are concerned, and they are also applicable to other varieties of neoplasms which have an equal or greater resistance to roentgen rays. But, when we have to deal with tumors composed mainly of cells which are much more sensitive to the rays than

epithelial cells, the validity of the principles established by Regaud and by Wood and Prime may be seriously questioned, and the applicability of the other physical factors which I have mentioned may also be questioned.

This is especially true of tumors derived from lymphoid cells which, as is well known, are exceptionally sensitive to roentgen rays. Elsewhere I have ventured to list the different varieties of normal cells in the order of their sensitiveness to roentgen rays,[1] and I have also attempted to give an approximate classification of neoplasms according to their sensitiveness.[2] Even a casual glance at these classifications is sufficient to make one realize that the sensitiveness of tumors agrees closely with that of the variety of normal cell of which each kind of tumor is mainly composed. If this is true—and a large body of experimental evidence and prolonged clinical observation has removed all doubt on this point—then it must be clear that the close agreement between the sensitiveness of any variety of cells and that of tumors derived from these cells cannot possibly be a result of coincidence. Thus the sensitiveness of tumors derived from lymphoid cells, such as the tumors which characterize Hodgkin's disease and lymphosarcoma, corresponds so closely to the sensitiveness of normal lymphoid cells (lymphocytes) in lymph nodes, in the circulating blood, in the spleen, in solitary lymph follicles in the intestine and in all other aggregations of lymphoid cells that it would be well nigh impossible to doubt that these cells are identical in both cases.

So important are these points that a radiologist who is thoroughly familiar with the relative sensitiveness of different kinds of cells and tumors can often make use of this knowledge to distinguish one variety of neoplasm from another, and in certain cases in which the opinion of a pathologist may conflict with the history of the patients' illnesses, with their clinical features, or with the effect of roentgen treatment, the effect of treatment may be more important than the unsupported opinion of the pathologist. Best of all, of course, is a critical correlation of all these elements.

How sensitive are the lymphoid cells? Among the many investigations on animals let us take only a few outstanding ones. First were those of Heineke,[6–8] who, after exposing to roentgen rays the entire body of a large number of mice, found, in all the mice which had thus been exposed, a rapid destruction of lymphocytes in the lymph nodes, spleen, circulating blood and other collections of lymphoid cells. These experiments—and many others which were made—showed that lymphocytes are more sensitive than all other cells, but they did not give an accurate idea of the extreme sensitiveness of these cells. Warthin undertook to study this problem further, and the importance of his experiments rests on the fact that he arranged his technique in such a way that sections of lymph nodes and other lymphoid structures could be obtained and could be examined microscopically within half an hour, and sometimes within fifteen minutes, after the animals had been exposed to the rays. Even after such a short time, he observed some destruction of lymphocytes. Under these circumstances, one can hardly speak of a latent period. When cellular destruction can be recognized through a microscope within fifteen or thirty minutes, the effect of the rays on the cells must have started during exposure.

Interesting as are these experiments of Warthin because they show how sensitive these leukocytes are, they do not give an absolute measure of the extreme degree of their sensitiveness. Other experiments have been carried out at two well known universities in this country during the past few years but, to my knowledge, the results have not yet been published (personal communications). One series of experiments showed that a surface dose of 15 roentgens is sufficient to cause perceptible destruction of lymphoid cells in lymph nodes. In the second of these investigations it was found that a dose of 10 roentgens

is sufficient to destroy some of these cells. Further comment is hardly necessary.

What does all this have to do with roentgen treatment of Hodgkin's disease or lymphosarcoma?

CLINICAL CONSIDERATIONS

The most essential point in treating patients who are afflicted with Hodgkin's disease or lymphosarcoma is a sound knowledge of the clinical features of these conditions, and the greater this knowledge the better.

Hodgkin's disease and lymphosarcoma are more common than earlier writers have led us to believe. This is probably because these conditions begin so insidiously; because, in the past, they were often mistaken for other conditions, such as tuberculous adenitis, and because, even now, in some cases the disease is not recognized until the pathologic process has reached a rather advanced stage. Another reason is that too much attention has been concentrated on the lymph nodes in the neck, armpits and groins.

In a considerable proportion of cases these forms of lymphoblastoma begin in the cervical nodes and thence extend to other groups of nodes. In some cases they begin in the nasopharynx, nasal accessory sinuses or tonsils. When the structures mentioned are involved, it is often assumed that the malignant process began there but, as often as not, the process may have been active in other parts of the body, notably in the retro-abdominal nodes, long before secondary invasion of structures in the head or neck developed. Therefore, when the nasopharynx, accessory sinuses, tonsils, or cervical lymph nodes are affected, this may be the primary site of the pathologic process, but it may represent secondary involvement.

The rapidity with which the cervical nodes enlarge and the size which they attain vary greatly in different cases. At the beginning and sometimes for long periods (several months or several years), the affected nodes enlarge for a time and then recede, and this cycle may be repeated indefinitely. Many patients are abnormally subject to infections of the upper respiratory tract; after each infection of this kind, the affected lymph nodes tend to enlarge for a time and then to recede again. When this occurs, patients often think the nodes have disappeared; usually they have not disappeared but they have diminished in size until the patients are no longer aware of their presence. As these cycles tend to recur from time to time, the size of the affected nodes tends gradually to increase. In some cases they may remain small for a long time, and then, for some obscure reason, they begin to enlarge and may reach considerable proportions in a short time. The cervical nodes may thus attain the size of olives, of plums, or even of lemons. In other cases they never become so large and in certain cases they remain small throughout the course of the malignant process. The mere size of the nodes does not give any indication of the degree of malignancy or of the seriousness of the patient's condition. This is true, not only of the cervical nodes, but of lymph nodes in any other region.

Mediastinal Nodes. As far as the lymph nodes in the thorax are concerned, those in the mediastinum (right and left paratracheal nodes and tracheobronchial nodes or both) are most commonly involved. However, Hodgkin's disease or lymphosarcoma begins in the mediastinal nodes much less commonly than it begins in the head, neck or retro-abdominal nodes. In most cases, when the mediastinal nodes are invaded, the involvement of these nodes is secondary to similar, but earlier, involvement of lymph nodes in other regions.

When Hodgkin's disease or lymphosarcoma involves the mediastinal nodes, a roentgenogram of the thorax usually reveals a bilateral and roughly parallel widening of the mediastinal structures, which extends from the inlet of the thorax downward to the cardiac shadow, which it usually overlaps more or less. But excep-

tions are not uncommon. Sometimes the nodes mainly affected are in one side or the other of the mediastinum, and the roentgenologic appearance may make it difficult to be certain whether the lesion is lymphoblastomatous or carcinomatous, a teratoma, a neurofibroma, or perhaps a dermoid tumor. Sometimes, enlargement of mediastinal nodes may be bilateral and ovoid in shape, and again the distinction between lymphoblastoma and carcinoma or some other tumor cannot be made with certainty from the roentgenologic appearances alone. In some cases the lymphoblastomatous character of the lesion can be recognized by other clinical features, such as enlargement of nodes in the neck or armpits, with or without involvement of the retroperitoneal and inguinal nodes. In other cases, however, such associated features may not be present. Then it is that irradiation of the mediastinum may, by causing a characteristically rapid regression, not only relieve the patient's symptoms but give a reliable clue to the pathologic character of the tumor.

Occasionally, the principal involvement is high in the mediastinum, and the symptoms may include not only dyspnea, with or without dysphagia, but also a brassy cough, hoarseness from involvement of one or both recurrent laryngeal nerves, puffiness and semicyanosis of the neck and face, and prominence of the superficial veins due to venous obstruction at or near the inlet of the thorax. The cervical nodes also may be abnormally large but, owing to the puffiness and engorgement, they may be difficult to perceive with certainty. The physician who is "thyroid conscious" may think that the roentgenogram suggests substernal extension of the thyroid, but the prompt regression of the growth and relief of the symptoms during and after irradiation may show this also to have been essentially lymphoid in character.

In some cases of mediastinal lymphoblastoma, roentgenograms of the thorax show little, if any, widening of the mediastinal shadow, and yet the symptoms suggest more or less definite involvement of the tracheobronchial nodes situated in and around the angle of the tracheal bifurcation. The reason the roentgenograms do not show lateral projection beyond the edges of the composite shadow cast by the sternum and spinal column may be that the affected lymph nodes have an anteroposterior disposition.

Pleural effusion may be caused by partial obstruction of the inferior vena cava by enlarged nodes in the lower part of the mediastinum; because the adenopathy is concealed by the cardiac shadow, it may not be visible in roentgenograms. Or the effusion may be due to infiltration of the pleura. In such cases, effective irradiation requires that the fields be large enough to include the lower two-thirds of the mediastinum as well as the entire diaphragm. Involvement of this kind, however, usually occurs only when the pathologic process has reached a relatively advanced stage, and prolonged improvement can hardly be expected under these circumstances.

Rarely, Hodgkin's disease or lymphosarcoma may infiltrate the lungs in what approximates a miliary manner. That is, the infiltration is scattered more or less throughout the lungs in the form of small almost miliary foci. Infiltration of this kind indicates that lymphoblastoma has invaded most or all of the small aggregations of lymphoid cells situated at the junction of the smaller branches of the bronchi. This form of infiltration also is a relatively late complication. Nevertheless, thorough irradiation may result in pronounced improvement; the duration of improvement varies with the circumstances in each case.

Sometimes, when lymphoblastoma affects the mediastinal nodes, the patient complains of pain in the thorax, which may extend to one or both upper extremities. Occasionally, the pain may be confined to the extremities, and pain in the thorax may not be present. Roentgenograms may show obvious or even marked

involvement of the nodes, but in some instances evidence of mediastinal involvement may be slight or actually uncertain. Under these circumstances, it is important to exclude, by careful examination, the possibility that the pain may be due to pressure irritation or actual infiltration of branches of the brachial plexus on one or both sides by lymphoblastoma affecting some of the cervical nodes or nodes in the upper part of the axillary (infraclavicular) space. If this possibility can be excluded, then the treatment should be directed to the mediastinum, as already suggested.

By physical examination alone, as most physicians know, it is often difficult or impossible to recognize intrathoracic involvement in these conditions; even when roentgenoscopy or roentgenography is employed, it may be impossible to distinguish Hodgkin's disease or lymphosarcoma from other neoplastic processes, such as carcinoma, neurofibroma, fibrosarcoma, teratoma, dermoid cyst, thymoma or the so-called Pancoast tumor. This is especially true during the early stage, but it is often true at any stage. One reason for this difficulty is that different kinds of tumors in the thorax can grow in such a way as to produce very similar roentgenologic signs. While, in most cases, Hodgkin's disease or lymphosarcoma involves nodes in both sides of the mediastinum and, consequently, produces a bilateral shadow which usually is nodular, lobular and more or less typical, it is not rare for these conditions to involve the nodes in one side much more than those in the other side, or even, as far as roentgenologic appearances go, the involvement may appear to be confined to the nodes in one side of this region. Sometimes, either in their original form or by some of the peculiar vagaries which may arise during their course, these forms of lymphoblastoma can simulate many other malignant neoplasms as well as some inflammatory conditions.

Retroperitoneal Nodes. Lymphoblastoma begins in the retroperitoneal nodes much more frequently than is generally supposed. but even when this form of malignant growth begins in the cervical or mediastinal nodes, or elsewhere, it often extends sooner or later to the retroperitoneal nodes. In 1939 I[3] drew attention to the clinical importance of these nodes and to the great variety of symptoms which their involvement in Hodgkin's disease and lymphosarcoma can cause.

When the para-aortic or mesenteric nodes become affected by lymphoblastoma, the symptoms at first and for some time may be so slight and vague that their recognition is difficult. Moreover, they vary considerably in different cases. These symptoms may consist of a tendency to bloat and belch after eating, distress in the upper half of the abdomen after meals, and loss of strength, which patients usually express as tiring easily, loss of endurance, or loss of "pep." As months or years elapse these symptoms tend gradually to increase, and others develop. The latter may include a sense of heaviness or of weight in the epigastrium, especially after eating, increasing difficulty in eating a full meal; pain in the epigastrium, which may recur after each meal; an increasing tendency toward constipation; pain in the lower thoracic, lumbar or sacral portions of the back, often extending to one or both hips or down one or both lower extremities; fever occurring in periodic bouts at varying intervals or continuing steadily, although with variations in intensity; regional and later general itching, with or without cutaneous lesions, which may be mistaken for urticaria, impetigo, scabies and so on. I shall not discuss these symptoms further except to mention that they may occur in different combinations and that some of them represent absolute signs that the retroperitoneal nodes have become involved.

When a patient is known to have Hodgkin's disease or lymphosarcoma, fever or itching, or both, mean that the condition has invaded the retroperitoneal nodes. A combination of two or more of the other

symptoms mentioned may mean the same thing, but the evidence is not so conclusive. Proof of the foregoing is to be found in the fact that, if the retro-abdominal nodes are properly treated, the fever, itching and cutaneous disturbances, when present, diminish or disappear soon after treatment, unless the pathologic process has reached an advanced stage or has entered the terminal phase. With few exceptions, and then never to the same degree, this effect is not observed when the treatment is directed toward regions other than the abdomen.

Variation in the abdominal symptoms in different cases probably depends on the particular nodes or group of nodes which are most involved and on the anatomic relationships of these nodes to various abdominal organs or structures. Sometimes lymphoblastoma may affect chiefly the upper para-aortic nodes. These are situated in the region of the celiac axis and are thus immediately behind the stomach, pancreas and duodenum, and in close proximity to the diaphragm or to the mouth of the thoracic duct. It is not surprising, therefore, that when some of these nodes become abnormally large they may give rise to pressure disturbances in any of the structures mentioned. They may crowd the liver and spleen forward and downward. When these nodes enlarge in an upward direction, they may press on the diaphragm and cause dyspnea, or they may interfere to some extent with the action of the heart. Sometimes enlargement is mainly in a posterior direction, causing pressure erosion of some of the lower thoracic vertebrae, or the pathologic process may infiltrate the intervertebral spaces, may thus extend into the spinal canal, and even invade the cord.

In other cases the para-aortic nodes mainly affected are below this level, and the pressure disturbances are most likely to concern branches of the lumbosacral plexus, the small intestine, the colon, the ureters or kidneys, and the lumbar vertebrae. Sometimes the nodes principally involved are lower still; they may be situated around the bifurcation of the great abdominal vessels or along the common iliac vessels. Rarely, the iliac nodes may become large enough to cause pressure erosion of the wing of the ilium. Rarely, also, the nodes mainly affected may be those along the internal iliac vessels; the symptoms may then be referable chiefly to some of the pelvic structures, such as the ureters, bladder or rectum.

As involvement of the retroperitoneal nodes by lymphoblastoma progresses, not only the para-aortic nodes but the mesenteric nodes also may be invaded. Sometimes, in fact, the involvement finally becomes so extensive that practically every structure containing lymphoid tissue is infiltrated more or less. This, of course, is most likely to occur in the late stages.

In order to treat most effectively lymphoblastoma affecting the retroperitoneal nodes, it is important to recognize these different possibilities or probabilities and to arrange the treatment accordingly. When the nodes chiefly affected are those along the abdominal aorta, between the bifurcation and the diaphragm, two large anterior fields, extending from the junction of the ensiform cartilage to the sternum down to just below the level of the umbilicus, and two corresponding posterior fields, are sufficient. But when the involvement includes the iliac and inguinal nodes, four anterior and four posterior fields are required. When, as occasionally happens, the iliac and inguinal nodes are chiefly involved, the treatment is best given through two low anterior and two corresponding posterior fields; in this case the anterior fields should extend well below the inguinal fold, so as to include the nodes in Scarpa's triangle.

Certain exceptions, however, should be considered. When retroperitoneal involvement is minimal or uncertain, or when the general condition is such that ability to tolerate more thorough irradiation seems doubtful, it may be advisable to give only limited treatment so as to bring about improvement without taxing the

patient's tolerance. Later, after the general condition has improved, more thorough treatment can be undertaken. In these cases the first course of treatment may be given through two or four posterior fields only. When the patient is thin or when the contour of the trunk is relatively flat from front to back, the same distribution of fields may be adopted with advantage.

In women aged less than forty years, when evidence of pronounced involvement of the iliac nodes cannot be found, neither the anterior nor the posterior fields should extend below the level of the crest of the ilium. Otherwise, artificial menopause may be induced, and this only adds to the patient's difficulties.

Irradiation of the abdomen tends to influence the leukocytes even more than does irradiation of other parts of the body. Hence, when this region is treated the leukocytes should be watched more closely than ever. At the Mayo Clinic, daily blood counts are the rule when irradiation of the abdomen is employed. As the treatment proceeds, the number of these cells tends to decrease; often this decrease is not steady and considerable fluctuation may be observed from day to day. Sometimes, on account of leukopenia, the treatment may have to be discontinued for one or two days, or abandoned altogether. The leukocyte count may remain abnormally low for periods which may vary from two or three weeks to two or more months, and this may interfere with subsequent treatment. Then the number of these cells tends to increase until it again reaches the normal level. The rapidity with which leukopenia develops, its duration, and the rate of regeneration vary greatly in different cases and depend on a number of factors, such as the stage of the malignant process, the volume of body tissues subjected to treatment, the regions treated, and the dose of radiation given to each field, as well as the total dose. Besides these factors, individual variation plays an important part. Occasionally a patient is encountered in whom leukocytic regeneration is extremely slow or in whom leukopenia may continue indefinitely.

An interesting, and sometimes an important, point to remember is that, when lymph nodes in the axilla are affected by these conditions, the mediastinal nodes also are usually involved. The reverse is often true but this is less common. In some cases involvement of the mediastinal nodes cannot be demonstrated easily because they have not become sufficiently large to project beyond the borders of the sternum and spinal column. Similarly, when the inguinal nodes are affected, it can almost be taken for granted that the retro-abdominal (para-aortic, mesenteric or iliac) nodes also are involved. In 1939 I[3] drew a attention to these points, and since then Symmers (1944) has confirmed their validity by extended observations at necropsy.

Unusual Complications. Among the many unusual complications which develop in certain cases of Hodgkin's disease or lymphosarcoma may be mentioned nodular infiltrations of the scalp or skin or diffuse infiltration of subcutaneous tissues in the axilla, breast, or other regions; infiltration of the orbit, of the lids, or of the eyeball itself; extension of the pathologic process from the mediastinal nodes to the subcutaneous tissues over the upper part of the sternum, where it may form a mass the size of a fist or of two fists; infiltration or erosion of a bronchus by adjacent mediastinal nodes; infiltration of a ureter, of the renal pelvis or of the kidney itself, with displacement, dilatation, hematuria, and hydronephrosis or pyelonephritis; infiltration of the suprarenal glands, with increased pigmentation of the skin; infiltration of the cerebral meninges or of the brain, and infiltration of the rectum which may have the form of polyps or which may simulate carcinoma.

Lesions of Bone. Not infrequently, certain bones may undergo destructive changes; this is prone to occur in the spinal column, where, as the result of increasing pressure exerted by enlarging retro-abdominal or mediastinal lymph nodes, one or more

vertebrae may be affected more or less. Similar erosive destruction may occur in the ilium because of the increasing pressure of affected iliac nodes. Sometimes, instead of erosion by pressure, diffuse osteoporosis of the spinal column or of other bones may develop, but the factors which are responsible for the loss of calcium are not understood. Less commonly, destructive changes in a bone may result from extension of the malignant process to the marrow.

The Blood. In many cases the number of erythrocytes and leukocytes is approximately normal. In other cases, especially when the retroperitoneal or mediastinal nodes are affected, the number of leukocytes may increase to 12,000, 15,000, 20,000 per cubic millimeter, or even more. In some cases, on the contrary, the number of leukocytes may diminish to 5,000, 4,000, or even less. In some cases the number of lymphocytes, monocytes, or eosinophils becomes abnormally high. As a rule, the number of erythrocytes remains normal for a long time but, when the malignant process reaches an advanced stage or approaches the terminal phase, some degree of anemia develops and gradually tends to increase until the patient dies. When the pathologic condition reaches an advanced stage, some patients begin to bleed from the nose, from the gums, from the respiratory tract or from the gastrointestinal tract, and some die primarily from hemorrhage.

TREATMENT

Treatment, if it is to yield maximal improvement, must be arranged so as to deal most effectively with the lesions which are responsible for the outstanding symptoms. The patient's chief symptoms should always be given due consideration, but often symptoms which he may regard as minor or as not related to his illness may actually be more important than the presenting symptoms. Before the treatment can be arranged, therefore, the entire situation should be considered as a whole. Treatment should first be directed toward the region of major involvement; this may or may not coincide with the patient's chief symptoms. Then, regions of relatively minor involvement can be treated. When the history of the patient's illness has been carefully and completely recorded, and when it is correlated with the physical and other findings, one should have a good idea of the situation.

Cervical Lymphadenopathy. When the cervical nodes are small or moderate in size, and when the nodes in other regions are not affected, irradiation of a single field on each side of the neck (Fig. 1) may be sufficient. When the involvement is confined to the nodes on one side of the neck, treatment should, of course, be limited to a single field on the affected side.

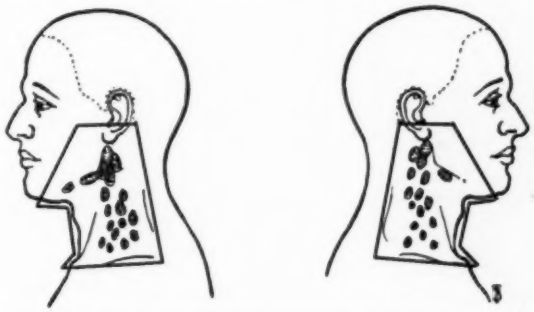

Fig. 1. Fields of roentgen treatment over each side of the neck when the cervical nodes are only slightly or moderately enlarged.

When the lymphadenopathy extends throughout the length of the neck, and especially when the submental, submaxillary, preauricular and postauricular, or occipital, nodes are involved, or when the patient's neck is unusually long, the region may be too large to be included in a single field on each side. In such a case, each side must be divided into two fields (Fig. 2). When the nodes have become very large and form a massive chain from the level of the ear to that of the clavicle, the best results may require two or four fields on one or both sides (Fig. 3). In this event the neck is divided as evenly as possible by a line extending from the lobe of the ear, or higher, down to about the middle of the clavicle; the width of the fields depends on the size of the neck and extends

from this line to the median line anteriorly, and posteriorly to a line which follows the hairline downward and includes the anterior border of the trapezius muscle. The two or four beams of rays are directed so as

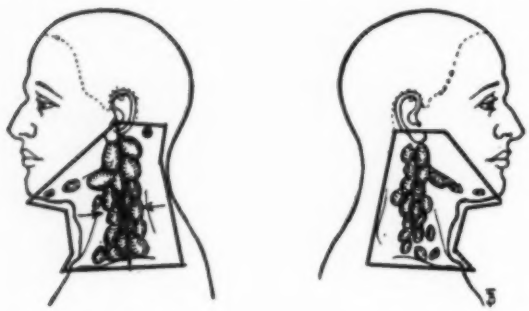

FIG. 2. The fields of roentgen treatment when the cervical nodes on the left side are numerous and rather large while the right cervical nodes are only moderately enlarged (two fields on left side and one field on the right side).

to converge on the enlarged nodes from either side of the central dividing line.

When, as not infrequently happens, the nasopharynx, pharynx or tonsils are primarily or secondarily involved, the treatment must take into consideration not only the affected structures on one or both sides but also the extent of involvement

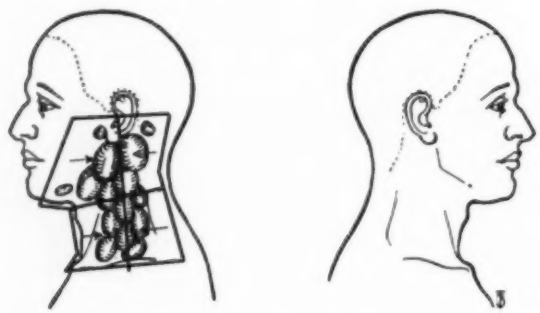

FIG. 3. Four fields of roentgen treatment on the left side of the face and neck when the left cervical nodes are greatly enlarged.

and the thickness of the neck and face. Effective treatment may be possible through a single field on one side, or it may be necessary to arrange the treatment through two lateral fields on one or on each side (Fig. 4). Sometimes the malignant process may have extended to one of the antrums or to the other accessory sinuses. In this event, one or two additional anterior fields may have to be provided. Of course, extensive involvement such as this usually occurs only when the pathologic process has reached a rather advanced stage. Substantial improvement may result even then, but the improvement is not likely to last as long as it does when the condition is less advanced.

Axillary Lymphadenopathy. In many cases, the axillary nodes are not perceptibly enlarged and do not require treatment. In other cases these nodes are slightly or moderately enlarged; in this

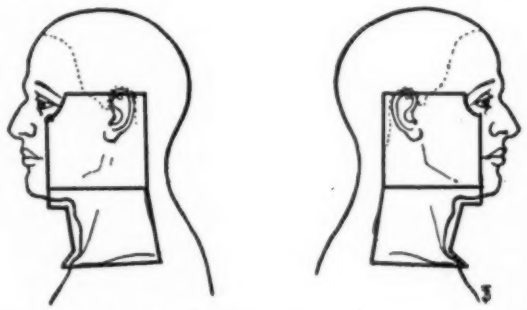

FIG. 4. The fields of roentgen treatment when Hodgkin's disease or lymphosarcoma has invaded the nasopharynx or tonsil. This is in addition to the lower fields through which treatment is given to the cervical nodes in the lower half of the neck.

event, satisfactory treatment can be given through an axillary field on one or both sides, the patient being placed, and the arm raised, in such a way that the rays can be directed into the axilla at an angle corresponding to the axis of the axillary space. Sometimes many nodes throughout the axillary space, from the clavicle to the armpit, may be affected; then, it is best to irradiate the entire axillary space on one or both sides through an axillary field and also through an anterior field which includes all the tissues from the clavicle to the armpit. In extreme cases, it may be advisable to add a third, posterior, field.

Mediastinal Lymphadenopathy. When treatment is directed toward the mediastinum and is arranged through a single

anterior, central field or through an anterior and a corresponding posterior field, it is usually followed by slight or moderate regression of the nodes and improvement in the respiratory and vascular symptoms, but the improvement seldom lasts long. Much greater and more lasting regression and improvement can be obtained by irradiating the affected intrathoracic structures through two large anterior and two corresponding posterior fields (Fig. 5), when these four fields are well placed, when the four beams of rays converge on the mediastinum, and when a sufficient dose of radiation is given within a reasonably short time. The upper

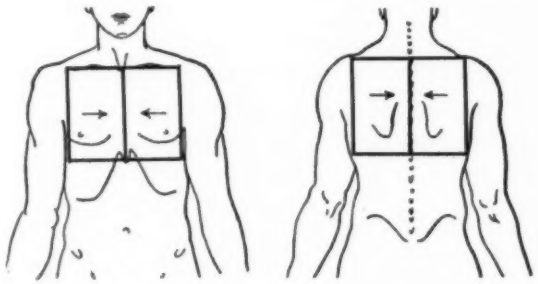

Fig. 5. Arrangement of the fields when roentgen treatment is directed toward the mediastinum and inner third of the lungs.

limits of the fields should correspond to the level of the suprasternal notch, and their lower limits should correspond to the level of the ensiform cartilage. Laterally, or transversely, the fields should extend from the median line to the anterior or posterior axillary line, as the case may be. The degree of convergence of the beams of rays varies according to whether involvement is confined to the mediastinal and hilar nodes or whether the malignant lymphoid process extends toward or to the chest wall.

Retro-abdominal Lymphadenopathy. When the pathologic process affects mainly the para-aortic nodes in the upper half of the abdomen, especially those in the region of the celiac axis, treatment should be directed toward this region through two large anterior fields and two corresponding posterior fields. These fields should extend longitudinally from the level of the ensiform cartilage to that of the navel, and transversely from the median line to the anterior or posterior axillary line (Fig. 6). When all the abdominal nodes (para-

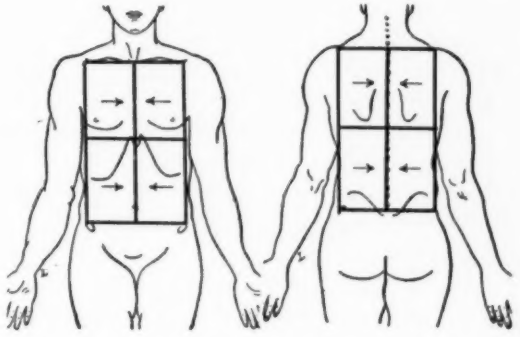

Fig. 6. Arrangement of the fields when roentgen treatment must be directed not only to the mediastinum but also to the upper two-thirds of the abdomen.

aortic, mesenteric and iliac nodes) are involved, the entire abdomen should be treated through four large anterior and either two or four posterior fields (Fig. 7), according to the circumstances in each case. When the inguinal nodes also are involved and require treatment, the line

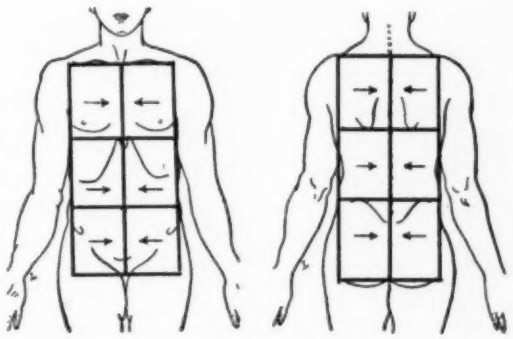

Fig. 7. Arrangement of the fields when roentgen treatment must be directed not only to the mediastinum but to the entire abdomen.

dividing the two upper abdominal fields from the two lower fields should pass a little below the navel, and the lower fields should extend downward so as to include all of Scarpa's triangle.

Quality of Roentgen Rays. Because the consensus now is that difference in wavelength per se does not influence the effect of the roentgen rays, it is generally assumed that all tumors, and even inflammatory lesions, may be treated with rays of the same quality, generated usually at or about 200 kv. Some radiologists even use rays generated at voltages between 400 kv. and 1,000 kv. Roentgen rays generated at 200 kv. or more have the advantage of delivering a greater dose at a depth of, say, 10 cm.; they induce less severe cutaneous reactions, and, at the higher voltages, they tend to induce less radiation sickness. These advantages may be of considerable importance in treating relatively resistant tumors, such as epithelial tumors of the uterus, bladder, prostate gland or rectum, but in treating Hodgkin's disease, these apparent advantages may lead one to overlook other factors which may be even more important.

The lymphoid cells, which are such important features of lymphoblastomatous tumors, are much more sensitive to roentgen rays than is generally realized. Therefore, effective treatment does not require the maximal dose of radiation in a given time that is required for tumors made up chiefly of epithelial cells. When the enlarged nodes are relatively superficial, as in the neck, armpits or groins, the level of absorption also becomes important. The greater the proportion of a beam of rays which penetrates the body to a depth of 10 cm., the smaller is the proportion of this beam absorbed by the first 3 cm., and vice versa. When treatment is directed against enlarged nodes in the neck, armpits or groins therefore, roentgen rays generated at a voltage of 130 or 140 kv. are more effective because a greater proportion of the rays are absorbed by the affected nodes. Even when the nodes are very large, rays generated at this voltage are often, although not always, more effective than those generated at 200 kv. or more. When, owing to massive enlargement of the nodes, it becomes important to produce the greatest effect in a short time, this can usually be done more effectively by increasing the number of fields, and therefore of beams of rays, than by increasing the voltage.

When the problem is to treat enlarged nodes in the mediastinum or abdomen, the tendency again is to employ roentgen rays generated at 200 kv. or more. In some cases especially when the patient is a person of unusual size or exceptionally obese, the more penetrating rays may produce the most favorable result, but in the average case rays generated at a medium voltage (130 or 140 kv.) will be found as effective, and often more effective, provided the number, size and position of the fields are carefully planned, and provided the beams of rays are well directed.

For many years, I have had ample opportunity to observe the different effect of roentgen rays generated at 200 kv. or more and of those generated at a potential between 130 and 140 kv. Moreover, clinical tests of treatment carried out at the two ranges of voltage convinced me of the superior effect of rays of moderate wavelength, and extended observation of patients treated by other radiologists with rays of shorter wavelength has only served to strengthen this conviction. In all probability the difference is not due to the difference in wavelength per se, but it is due partly to a difference in the quantity of rays absorbed, partly to the great sensitiveness of lymphoid cells, and perhaps also to other factors which are still obscure. It seems likely that these "obscure factors" consist mainly in a difference in the quantity of rays. When treatment is given with roentgen rays generated at 200 kv., the affected lymph nodes usually do not retrogress so much and, especially when the same region is treated repeatedly, diffuse induration tends to develop and the lymph nodes rapidly become resistant to further treatment. For these reasons, the treatment must be given up after a relatively short time; this is especially true when each field is exposed to an excessive

quantity of rays. When, on the contrary, treatment is given with roentgen rays generated at moderate voltage (130 to 140 kv.), diffuse induration of the tissues in the exposed fields is less likely to occur and the affected nodes continue to respond to treatment for a longer time. This applies to lymph nodes in the abdomen and mediastinum as much as to those in the neck, armpits, and groins. When an excessive quantitative dose of roentgen rays generated at moderate voltage is given to any field, especially when this is repeated a number of times, induration of the skin and subcutaneous tissue is likely to develop, but usually this develops more slowly. When excessive doses are avoided, diffuse induration does not develop and the affected nodes continue to respond for a long time. It is apparent, therefore, that the quantity of roentgen rays (surface or skin dose) is an important element.

As Duane pointed out many years ago, when roentgen rays generated at moderate voltage (130 to 140 kv.) are employed, aluminum is a more efficient filter than copper. When the cervical nodes are moderately enlarged, 4 mm. of aluminum is used as a filter. When nodular infiltrations of the scalp or skin must be treated, 4 mm. of aluminum provides adequate filtration. When the cervical nodes are large and numerous, an aluminum filter 6 mm. thick is preferable. When treatment is directed toward the mediastinal or retro-abdominal nodes, 6 mm. of aluminum should be used.

Exceptionally, such as when the nasal accessory sinuses, the nasopharynx or the tonsil are involved, roentgen rays generated at 200 kv. or more and filtered through 0.75 mm. of copper and 1.0 mm. of aluminum yield superior results.

Quantity of Roentgen Rays. Because in epithelial and other tumors effective destruction of the malignant cells requires the largest dose of roentgen radiation which can be given with safety, it is widely assumed that the same is true of all malignant processes. When lymphoblastoma is limited to a single region, and especially when it is confined to a small cluster of nodes, the hope of effecting a permanent cure may reasonably be entertained, and a complete result can sometimes be achieved. Even then, however, doses of the order of those required for epithelioma are not necessary. The lymphoid cells in the affected lymph nodes are usually so sensitive to the radiation that much smaller total doses are sufficient.

Occasionally, when the pathologic process appears to be confined to a single group of nodes, the attempt to effect a permanent cure by concentrating the maximal dose of radiation on the affected nodes may be justified. In the great majority of cases, when the patient consults a physician, the malignant lymphoid process has already invaded two or more groups of nodes in different regions. Not infrequently, the process has already reached an advanced stage in its course, and sometimes it is already near or actually in the terminal phase. Under these circumstances, a cure is impossible, and the most that can be expected is a variable degree of improvement for a variable period of time. When lymphoblastoma is not too advanced, and especially when it has a relatively chronic form, the patient's condition is susceptible of great improvement, and he may survive from five to twenty years, or even longer. In all these cases the aim of the radiologist should be to maintain this improvement as long as possible. This can seldom be achieved by the method of maximal total doses made possible by protracted fractional irradiation. To follow this course may yield excellent initial results and treatment may be repeated once or twice at the most. But when the pathologic process again becomes active, further treatment is impossible or, if it is undertaken, it has little if any effect and the patient no longer obtains relief.

A more effective method, in my estimation, is to give to each field, in one or two days, as large a dose of radiation as can be given without taxing the tolerance of the

skin and other tissues or of the patient as a whole. As a rule, such a dose is between 550 and 600 roentgens (surface dose, measured in air). The different fields are thus treated successively, one at a time, until all the fields have received the specified dose. The number of days required to complete the course of treatment depends on the extent of involvement and the number of fields to be irradiated, as well as on the tolerance of the patient. When a single cervical field requires treatment, this may be given in one or two days, but when most of the lymph nodes must be treated, from ten to sixteen days may be required. Many patients cannot tolerate 550 roentgens (one field) a day; this is especially true when treatment is directed toward the upper half of the abdomen. In this event it is advisable to give only 275 roentgens (half of one field dose) on successive days, treatment of each field being completed before another field is treated. Most patients can tolerate 275 roentgens a day without undue difficulty, but occasionally a patient can tolerate only 175 or 200 roentgens a day.

Time Distribution of Treatment. From time to time I have seen patients who have told me that they had previously been treated with roentgen rays for one month or for several months. When asked whether the treatment had caused the enlarged lymph nodes to recede and their condition to improve, they have replied that at first the nodes diminished slightly for a short time, but later the treatment remained without perceptible effect. Upon inquiring into the chronologic arrangement of the treatment, I was told that treatment had been given only once or twice a week. Yet, when these patients were treated according to the general scheme which I have described, the nodes regressed, and the general condition improved as rapidly and as much as if they had never been treated at all. Later, when the pathologic process again became active, additional treatment has again, and repeatedly, produced satisfactory improvement. There seems to be no doubt that the reason the previous treatment had yielded only slight and transient benefit in these patients was largely that the interval between sessions had been too long or that the quantity of roentgen rays given at each session had been too small. My own conclusion is that frequently both factors are responsible. Treatment once a week or even twice a week cannot possibly produce the improvement to which the patient is entitled.

Sometimes, the slight initial improvement and subsequent failure to improve are attributed to an increased resistance of the affected lymph nodes, but when these same nodes and these same patients improve satisfactorily under a different scheme of treatment, the assumption of increased resistance obviously does not rest on a sound basis. This problem of increasing resistance of cells has interested me for many years. As far as the lymphoid cells are concerned, the principal factor in increasing resistance to irradiation appears to be excessive quantitative doses. If these are avoided, and if clinical factors in each case do not account for increased resistance, the affected nodes and structures continue to respond for a long time. It is true that as time goes on, especially in the chronic form of lymphoblastoma, some increase in resistance gradually develops, but this is slow. In my experience, the main causes for failure of lymphoblastomatous lesions to respond are: (1) an advanced stage or terminal phase of the pathologic process; (2) excessive quantitative doses of roentgen radiation within a given time.

When the patient is first seen, two courses of roentgen treatment, with an interval of three weeks between them, may be sufficient to bring the pathologic process under control for a time. A single course of treatment may be followed by more or less marked improvement and this may continue for a certain length of time, but, when a second course is given three weeks later, the improvement is much greater and lasts longer. In other cases, especially

when lymph nodes in two or more regions are greatly affected, it is often advisable to give a third course of treatment three to six weeks after the second course. Then, the patient should not receive any more treatment for as long a time as possible, but he should be examined every three or six months. How often subsequent roentgen treatment may have to be given varies greatly in different cases. Some patients require additional treatment every few months, while others require treatment at longer intervals; some have to be treated only at intervals of two or three years, and some go even longer.

Pathologic Factors Which Influence the Effect of Roentgen Treatment. Occasionally a patient is encountered in whom the lymphoblastomatous tumors do not retrogress at the rate or to the degree expected. Frequently, this is because the pathologic process has reached an advanced stage or has entered the terminal phase. When failure of the enlarged nodes to retrogress as usual is not due to this factor, it can almost always be traced to one of the following causes: (1) the presence in the mass or masses of enlarged nodes of an exceptional proportion of connective tissue; (2) the presence of old calcified deposits in some of the nodes; (3) the presence of secondary infection. The first two factors seem to occur chiefly in mediastinal tumors, whereas the third factor seems to occur chiefly in the cervical nodes. All three, however, are uncommon.

Clinical Factors Which Influence the Effect of Roentgen Treatment. Besides the extent of involvement, two other factors have an important bearing on the results which may be expected from roentgen treatment. One is the relative acuteness or chronicity of the malignant process in each case. In some cases lymphoblastoma runs a comparatively short course, and the time which elapses between the apparent onset of the disease and the death of the patient may vary between six months and two or three years. In other cases the course of the process may extend from three to five or six years; these constitute the intermediate group. In still other cases the condition may persist from five to twenty years, or longer. In cases of relatively acute lymphoblastoma, roentgen treatment may be followed by exceptionally rapid regression, but this is of short duration. In the chronic cases, proper roentgen treatment is often followed by marked regression and prolonged improvement. These are the cases in which long remissions are obtained.

The other clinical factor is the stage of the malignant process. Sooner or later, in practically every case, the condition reaches an advanced stage in its evolution and finally enters the terminal phase. When this occurs, the enlarged lymph nodes or other diseased structures respond to roentgen treatment less and less. Usually, this failure of response is associated with other signs of advanced disease, but perhaps the best single indicator is the numerical status of the red blood corpuscles. As long as they remain at or near the normal level, the patient may be expected to derive improvement from roentgen treatment; but when their number begins to diminish more or less steadily, this is usually the beginning of the end. Death may not occur for six months or may be delayed for three years, but a more or less steady decrease in the number of erythrocytes usually means that the end is approaching.

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Vol. 54, No. 6

BIOLOGICAL EVALUATION OF 20 MILLION VOLT ROENTGEN RAYS*

I. ACUTE ROENTGEN DEATH IN MICE

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INTRODUCTION

THE betatron, which was invented at Illinois by Kerst,[3,4,5] is an instrument which produces roentgen rays of very high quantum energy. It is similar to conventional roentgen apparatus in that the radiation is the result of the collision of a stream of electrons with a metallic target. The fundamental difference lies in the mode of acceleration of the electrons. The conventional types of roentgen equipment involve the application of large voltages between electrodes, the electrons being accelerated by this potential difference. The betatron uses magnetic induction. The stream of electrons is curved into a circle by the action of a magnetic field and accelerated by increasing the strength of the field. After reaching a predetermined energy the electrons are made to strike a target, yielding a burst of roentgen radiation. In order to repeat the process, the magnetic field is reduced to zero. The cycle is repeated 180 times a second, producing as many bursts of radiation. In our experiments, the roentgen rays had a peak energy of 20 million volts.

The secondary electrons from high energy roentgen rays travel almost entirely in the direction of the primary beam and are much more penetrating than those from conventional roentgen rays. The range of a 20 megavolt electron is about 10 centimeters in water, as compared to ranges of about 3.5 cm. for 10 megavolts, about 1 cm for 1 megavolt, and about 1 millimeter for 200 kv. Thus, where high energy roentgen rays strike an object, the density of ionization, i.e., the depth dose, will increase to a maximum below the surface, and only from there on will it slowly decrease. Preliminary measurements[6] indicate that, for 20 million volt roentgen rays, at a target distance of 45 cm., the maximum depth dose occurs at a level of about 3 cm., and amounts to about three times the surface dose. Beyond the maximum, the depth dose falls slowly. At 10 cm., it is about 75 per cent of the peak dose, or 225 per cent of the surface dose. It follows that, if we were to irradiate a focus in the depth of the body with 20 million volt roentgen rays, the entry portal would receive a comparatively small dose while the exit portal would receive about 50 to 80 per cent of the tumor dose.

A beam of rays with a depth dose distribution as described must have a different effect from that caused by conventional rays if the irradiated object, as a whole, is large enough to register the peculiar depth dose distribution. Since the human body is large enough to permit the operation of this factor, it is to be expected that the betatron radiation will add new resources to the treatment of deep-seated cancer.

However, significant as the depth dose distribution is, it may not be the only difference of therapeutic importance. The effects of the high energy radiation may also vary in other equally important aspects which concern reactions occurring in any volume element, independent from the dosage distribution in the whole body. The effect on living tissue, in general, may be different in quality: there may be specific reactions completely foreign to those accompanying the use of the conventional roentgen ray. It must be remembered that qualitatively different absorption processes occur at the energy levels of the rays produced by the betatron. The effects on living tissue may be different in quantity: there may be a difference in doses required, a difference which may be a constant one, easily

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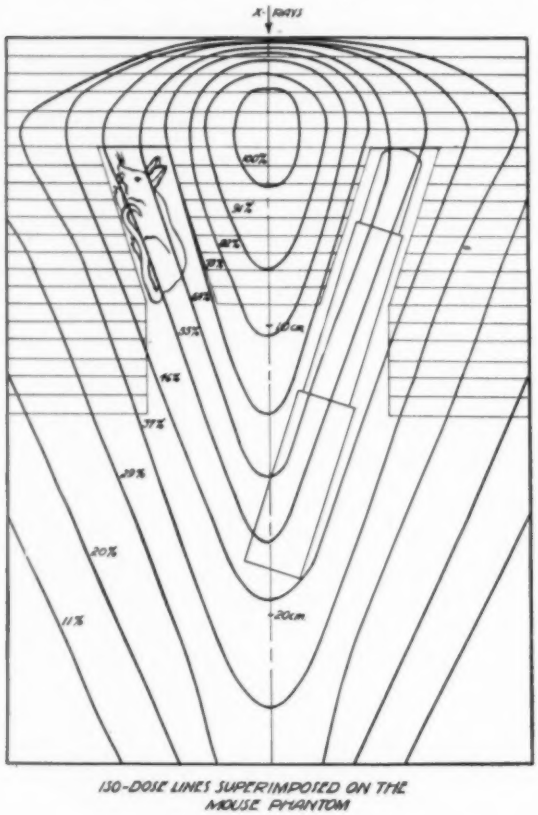
compensated by the use of a correction factor, or which may be found to vary differently for each particular tissue and reaction. Obviously, only biological experiment can answer these questions. The object, therefore, of this series of investigations is to compare the effects of a betatron



ISO-DOSE LINES SUPERIMPOSED ON THE MOUSE PHANTOM

FIG. 1. Isodose lines superimposed on the mouse phantom.

and a conventional deep therapy machine under experimental conditions where the differences in depth dose distribution are eliminated, thus isolating for study all other possible differences of action.

MATERIAL AND METHODS

As the first biological test object, we selected mice and submitted them to lethal doses administered homogeneously to the whole body. Mice have been used in biological dosimetry as early as 1912.[8] In recent times, Lawrence and Tennant[7] have used mice for the bio-assay of fast neutrons, and Ellinger[2] for the demonstration of backscattering. We considered mice a favorable object because their reactions could be checked in great detail with the vast information assembled on irradiation reactions in mammals; also, mice are small enough to allow nearly homogeneous irradiation, thus excluding any dosage distribution factors.*

The influence of the peculiar depth dose distribution was eliminated by irradiating the mice in a phantom designed to obtain approximately homogeneous dosage throughout the body of the animals. To determine the shape of the isodose surfaces in the phantom, a film, with 4 inches of presswood (density, 1.1) on each side, was exposed with the central beam passing along the center of the film.[5] The film was examined photometrically. Lines of constant density were regarded as isodose lines. The relative intensities were determined from the density characteristics of the film. With 20 million volt radiation, and a target distance of 70 cm. to the top of the phantom, the isodose lines are the curved lines in Figure 1.

The phantom was constructed of nine sheets of 16 by 16 by $\frac{1}{4}$ inch pressdwood which were bolted together, with six 1 inch holes drilled along isodose surfaces, as shown in Figure 1. Six sheets of the same material were added in front of the phantom, and six on each side in back in order to allow for backscattering.

The phantom was calibrated by inserting several Victoreen thimbles in various holes and observing the ratios of readings for a given exposure. In operation, a 250 r thimble was placed in one of the holes, and read approximately every 200 r, so that a measure of the dose given to each mouse was obtained. This dose was correct within ± 10 per cent, as established from the dose distribution curve and direct dosimeter readings.

After the irradiation, the mice were observed mainly in order to determine the survival time, i.e., the time elapsing between irradiation and death. In addition, the weight

* The animals used in these experiments were C57-Black mice. They were given to us by Dr. Herman B. Chase, of the Department of Zoology, University of Illinois. The mice were kept in wooden bins, on a diet of "Purina" dog chow and water.[1]

was taken daily, and general impressions recorded. After death, an autopsy was performed, and several organs preserved for pathological examination.

RESULTS

Mice subjected to total body irradiation with 20 million volt roentgen rays react, qualitatively, the same way as mice treated with 200 kilovolt rays. They lose weight, show anorexia and diarrhea, become anemic, their fur gets flurry, and they recover or die under progressive cachexia, depending on the size of the dose. Pathological examination reveals severe damage in many vital organs.[9,10] Within the range of our observations, we found in betatron mice all the reactions known to occur in mice treated with comparable doses of conventional roentgen rays, and no new, previously unknown effect.

The difference between the two radiations appears when the quantitative dose-response relations are considered. To obtain comparable reactions, higher doses are needed of the 20 million volt rays than of the 200 kilovolt rays, the doses being expressed in both cases in roentgens measured with the Victoreen thimble in a phantom, and the r per minute rates being of the same order.

The difference in effectiveness was established, quantitatively, by evaluating the relations between survival time and dosage. It has been found[9,10] that the survival time is inversely proportional to the square of the dose, for a dosage range from 650 to 1,175 r applied to mice weighing 20 gm. For mice of varying weight, subjected to constant doses, the survival time is directly proportional to the weight. Combining both observations one obtains the formula:

$$T.D^2/W = 2.3 \times 10^5$$

$$(2.1 \times 10^4 < D^2/W < 6.9^9 \times 10^4 \text{ r}^2\text{gm}^{-1}) \quad (1)$$

where T is the expected survival time, D the dose in r, and W the weight in gm. at the time of irradiation. The formula is valid only for a certain range of D^2/W viz., from 2.1 to 6.9×10^4 r^2gm^{-1}, always referring to our standard strain, C57-Black. Below and above this range, survival times remain constant despite considerable changes of dosage. Near the points of inflexion of the curve, the dose-response relations are ill defined. Thus, the range favorable for bio-assay is between values of dose^2/weight from 2.2 to 5.6×10^4 r^2gm^{-1}, or for an equivalent dosage range of another radiations.

The survival times in 35 mice killed by 20 million volt roentgen rays are assembled in Figure 2. The ordinate represents survival times, the abscissa the quotients "dose^2/weight" and, on a second scale, the corresponding doses for a mouse weighing 20 gm. The scales are logarithmic. Every symbol stands for an individual observation. The dashed line is the dose-response curve established for conventional 200 kv. roentgen rays.[9,10] The results obtained with the betatron can be adequately represented by a broken line parallel to the one found with 200 kv. rays, differing only in its relation to the dosage axis. The distance between the two curves yields the factor of equivalence between 20 million volt rays and 200 kv. rays. From Figure 2, the distance between the two curves equals 0.38 (logarithmic difference). Thus:

$$\log \text{Dose}^2 \text{ (betatron)} - \log \text{Dose}^2 \text{ (200 kv.)} = 0.38 \quad (2)$$

$$\text{Dose (betatron)} \times 0.65 = \text{Dose (200 kv.)}$$

i.e., 1 r of the betatron radiation is equivalent to 0.65* r of 200 kv. radiation, both radiations measured with the Victoreen thimble in a saturated beam, the effectiveness being defined with respect to the survival time of mice.

The reliability of the value 0.65 can be derived from a consideration of the deviations of actual survival times from the expected values, $T = \text{const.} \times D^2/W$ (see ref. 9 and 10). A statistical computation shows that the true value of the conversion factor lies in the range from 0.54 to 0.75 (with a probability of 95 per cent). A more accurate determination would neces-

* Some additional data have been obtained since this paper was written. From the total material at hand, at the present time, the best estimate of the conversion factor is 0.78.

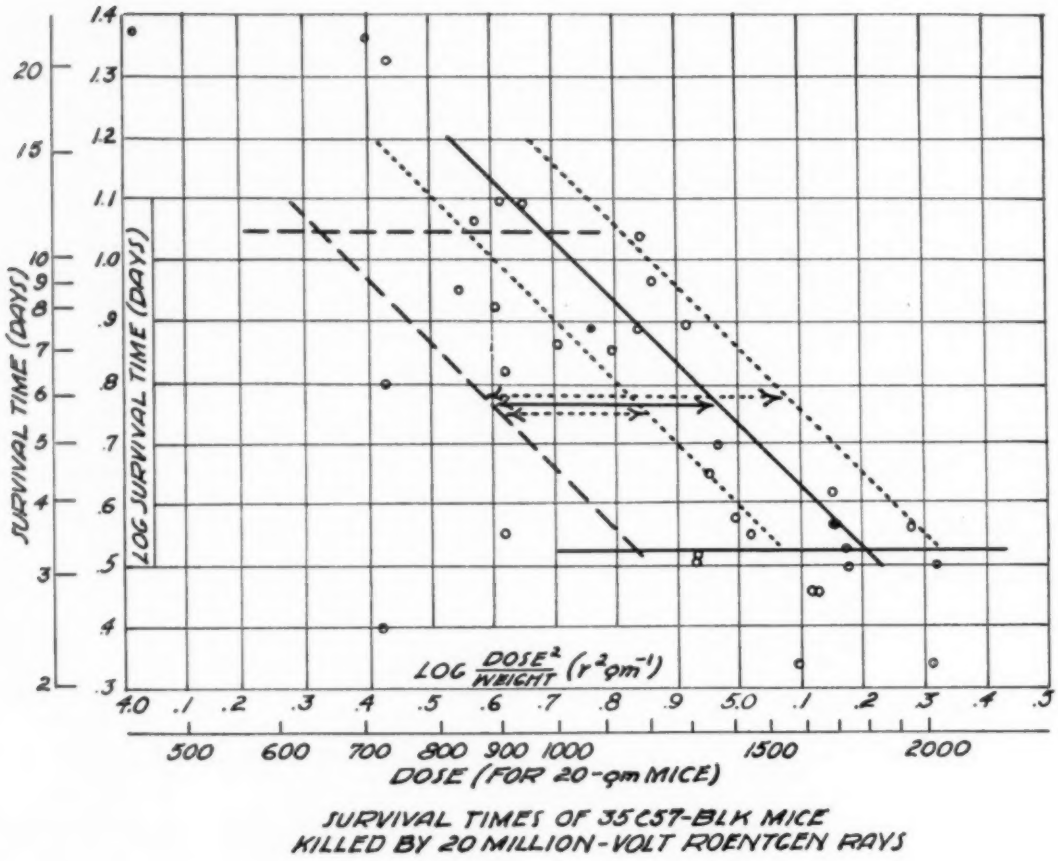

SURVIVAL TIME (DAYS)
LOG SURVIVAL TIME (DAYS)
LOG DOSE²/WEIGHT (r²gm⁻¹)
DOSE (FOR 20-gm MICE)
SURVIVAL TIMES OF 35 C57-BLK MICE
KILLED BY 20 MILLION-VOLT ROENTGEN RAYS

FIG. 2. Survival times of thirty-five C57-Black mice killed by 20 million volt roentgen rays. Ordinate—survival time; abscissa—dose²/weight, and corresponding doses for 20 gm. mice; symbols—individual observations; dashed line—dose-response curve for 200 kv. rays; heavy line—trend of the betatron results; heavy arrow—conversion factor; dotted lines and arrows—statistical margins of the estimates.

sitate much more experimentation, and was not considered useful at the present time.

The way the data were evaluated is based on the assumption that the survival time-dose relation has the same characteristics for both betatron and conventional rays. This assumption, in turn, rests on the fact that we have not found anything suggesting a qualitative difference in the actions of both kinds of radiation; the experimental data submit readily to this way of curve fitting. However, it is admitted that the betatron data as they stand do not suggest strongly the type of curve chosen. One might fit a straight line, instead of a Z-shaped broken line, to the experimental points. This procedure leads to factors ranging from 0.68 to 0.88. Generally speaking, all functions that can be reasonably used to represent the experimental data, lead to factors which are of the same order as our value of 0.65*, with differences too small to be significant at the present stage of investigation.

DISCUSSION

We regard the absence of specific betatron effects as the most significant result of these experiments. If further investigation confirms the belief that high and low energy roentgen rays act on biological objects qualitatively in the same way, it will be permissible to adapt to the betatron knowledge acquired with ordinary rays. Thus therapy will be possible soon, giving us the full advantage of the peculiar depth dose distribution.

The quantitative difference in effective-

* See footnote page 725.

ness thus far apparent cannot be disregarded. It is not large, nor is it negligible. It must be emphasized that the difference was found under specified conditions, using as a physical measure the discharge of the Victoreen r-meter, and as a biological measure the survival time of mice. Either of these measures may deviate from the absolute standard. The Victoreen thimble is an absolute dose indicator at ordinary energies, but it is not known how it reacts to 20 million volt roentgen rays. The biological measure may deviate from the absolute standard because of the qualitative differences in physical absorption processes. Furthermore, the spacing of the ion pair production is not the same for the two kinds of radiation, nor is the timing, the betatron rays coming in short intense bursts. However, no theory, based on our present knowledge, can be convincing. We must have additional experimental evidence, some of which we hope to procure in investigations now in progress.

SUMMARY

1. It can be predicted, on the basis of established depth dose curves, that the high energy radiation of the betatron will be useful in the treatment of deep-seated cancer.

2. It cannot be predicted how the betatron radiation will act on any element of living tissue.

3. The elementary actions of high energy roentgen rays must be established by biological evaluation, conducted in such a manner that the influence of the depth dose distribution is eliminated.

4. Mice were subjected to irradiation of the whole body with a homogeneous dose of 20 million volt roentgen rays.

5. Qualitatively, the clinical and pathological effects observed were the same as those attending the use of conventional roentgen rays.

6. A quantitative evaluation of effectiveness was obtained, using the Victoreen r-meter as a physical measure and the survival time of mice (between irradiation and death) as a biological measure. It was found that, under the conditions stated, 1 r of the 20 million volt rays of the betatron is equivalent to about 0.65*r of the conventional 200 kilovolt rays.

7. The significance of this conversion factor will be established only by further experimental investigation.

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We wish to express our gratitude to Professors D. W. Kerst and G. M. Almy, of the Department of Physics, and to Dr. Herman B. Chase, of the Department of Zoology, for their kind interest and generous help at various phases of this investigation.

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* See footnote page 725.

HOOKWORM DISEASE

A SMALL INTESTINAL STUDY*

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and
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FEW places in the world have a higher incidence of hookworm disease than the Province of Assam in India, where, according to Chandler,[1] 94 per cent of the individuals are infected. It was here that we gained our experience. Serving with a General Hospital in this area for over two years, we had ample opportunity to study hookworm disease as it developed in our American troops.

The purposes of this communication are to call attention to the fact that hookworm disease may produce changes in the small intestine early, and to describe the roentgen appearance of these changes. Whereas the statistical data presented were gleaned from the records of 74 patients, more than 125 were examined by roentgen methods. All had positive stools, but the hookworm species was identified in only 14 cases. Of these 8 were *Ankylostoma duodenale*, 2 were *Necator americanus*, and 4 were a combination of both.

In 1925, Henderson[3] described antiperistalsis in the duodenum which he considered a presumptive sign of intestinal parasitosis. More recently Yenikomshian and Shehadi[7] called attention to the fact that ankylostomiasis produced the clinical manifestations of duodenal ulcer which cleared after treatment by vermifuges. They observed alterations in duodenal peristalsis and mucosal pattern which they considered significant. The largest series of patients studied by roentgen methods was described in 1943 by Krause and Crilly.[5] They reported 97 young adults infested by *Necatur americanus*, all but 2 of whom were born and raised in southern United States. These authors concluded that the small intestinal pattern in ankylostomiasis simulated that described in the literature as the "deficiency pattern."

PATHOLOGY

In man, hookworm disease is usually due to *Ankylostoma duodenale* or *Necator americanus*. Whereas both are widely distributed throughout tropical and subtropical regions, *Ankylostoma duodenale* is more common in the Old World and *Necator americanus* in the New. The latter, however, is found frequently in India.

The life cycle of both species is about the same. When the eggs leave the bowel, they segment and form rhabditiform larvae which grow and moult, becoming small filariform larvae infectious to man. Under proper conditions these larvae become active and burrow rapidly through the skin of the exposed individual. They enter the veins and lymphatics which carry them to the heart and the lungs. Here the larvae penetrate the capillary and alveolar walls invading the air sacs, and eventually proceed up the bronchi and trachea to the epiglottis where they spill into the esophagus and are swallowed.[6]

Having reached the small intestine the larvae grow rapidly, becoming mature in about one month after entering the body. Here they develop mouth capsules and attach themselves to the intestinal mucosa from which they draw nourishment. Adult hookworms measure 10–12 mm. in length and 4–6 mm. in width (Fig. 1). They usually inhabit the distal duodenum, the jejunum, and the proximal ileum where mating occurs and new eggs are laid.

At autopsy the parasites are found at-

* From the 29th General Hospital, A.P.O. 689, c/o Postmaster, New York.

tached to the intestinal mucosa or lying free in the lumen of the gut. Small punctate hemorrhages mark the areas in which their mouths are embedded and through which they suck blood.

Lieutenant Colonel J. S. Forrester found active hookworm infestation at autopsy in a patient who died in our hospital of scrub typhus. It is noteworthy that the patient was a native of Massachusetts and had been in Burma but two months before he died. His past intestinal history was uneventful. The autopsy was done about two hours after his death. The following report was submitted to us by Lt. Col. Forrester.

The stomach and esophagus are essentially normal. The jejunal wall seems a little heavy and boggy but this is not marked. The external surface of the small gut reveals some areas of patchy capillary congestion. The colon is negative.

On opening the gut a moderate number of *Ankylostoma duodenale* are found still attached to the mucosa. The concentration of worms is greatest in the mid-jejunum where 2–4 worms are seen in each 2–3 inch segment. There are no worms attached to the mucous membrane beyond a point 12 feet proximal to the ileocecal junction. The contents of the bowel were washed and sedimented. A total of 260 adult *Ankylostoma* were found in the sediment; all but 5 came from the jejunum and upper ileum (Fig. 1).

No gross lesions are noticed where the worms are attached to the mucous membrane although there are petechiae in nearby areas. The mucosa of the gut seems almost normal. There are no ulcerations or hypertrophied Peyer's patches.

Microscopically a portion of a hookworm is seen near its point of attachment to the jejunal wall. The worm contains some leukocytes and red blood cells. The jejunal villi are slightly edematous, a finding also noted in the submucosa. Plasma cells, lymphocytes and an occasional polymorphonuclear leukocyte are distributed sparsely throughout the entire thickness of the wall of the jejunum (Fig. 2).

The mucosal changes may be more advanced than those described above. The punctate hemorrhages may break down forming small erosions or frank ulcerations which become secondarily infected and penetrate the submucosa.

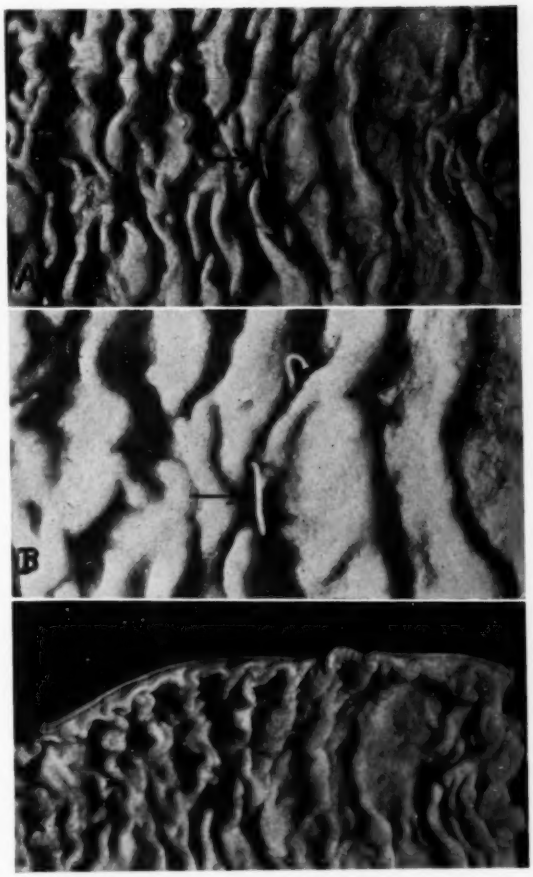

Fig. 1. Hookworm disease. Photographs of jejunum showing appearance of mucosal folds and hookworms. *A* reveals the normal or slightly accentuated appearance of the valvulae conniventes and several hookworms *in situ*. Close-up enlargement of hookworms seen in *B*. These were firmly embedded in the mucosa. Note the normal thickness of the wall of the intestine illustrated in *C*.

CLINICAL OBSERVATIONS

Krause and Crilly[5] divided their patients with ankylostomiasis into two groups: (1) those with significant symptoms whom they considered as having "hookworm disease," and (2) those in whom ova were an incidental finding which they called "hookworm infestation." Of the patients reported by Krause and Crilly 45 per cent had "hookworm disease" and 55 per cent, "hookworm infestation." Approximately

FIG. 2. Hookworm disease. Photomicrograph of jejunum taken from the region of the attached parasite. Portion of hookworm at *X*. The jejunal wall is slightly edematous. This section was taken from the specimen shown in Figure 1.

65 per cent of the patients we saw had clinical evidence of "hookworm disease." The rest were battle casualties or patients with other conditions in whom positive stools were found during routine studies.

The Americans treated for hookworm disease in our medical installation were in excellent health when they first arrived in the China-Burma-India Theatre of War. Approximately 80 per cent came from parts of the United States where hookworms were not a public health hazard. As we knew where and when they had traveled throughout India and Burma, it was easy to estimate when they were first exposed to the parasite. This, plus the clinical history, made it possible to judge the duration of the disease with considerable assurance. We felt reasonably confident, therefore, that the disease, as we saw it, was of recent origin. In 80 per cent the disease was believed to be less than three months in duration. The remaining cases were from six to eight months in duration; one patient was thought to have had the disease for approximately one year.

The recent past medical history in our patients was interesting. It was noteworthy how often the men remembered itching after lying in foxholes for several hours. Their descriptions of the "ground itch" were classical and it was by no means uncommon for them to volunteer that the itching was localized to that part of the body exposed to water or mud. The pruritus and dermatitis usually developed several hours after exposure and lasted from four to seven days.

Cough, too, was common. Indeed it occurred with such regularity in combat areas that men called it the "foxhole cough." It was potentially dangerous as it could expose their position to the enemy. The cough was usually dry and superficial, appearing one to two weeks after the "ground itch." The chests of many were examined

during the period of their gastrointestinal complaints, but no roentgen abnormalities were noted.

The onset of the gastrointestinal symptoms varied from six to twenty-five weeks after exposure. In many patients the disease was ushered in by an acute attack of nausea, vomiting, abdominal pain and diarrhea. In others, abdominal complaints developed gradually and were associated with marked weight loss and intractable diarrhea.

Pain was the most prominent intestinal complaint. It was usually epigastric and sometimes suggested peptic ulcer. In general, the pain was diffuse and was variously described as "burning" or "cramping" in character. As a rule, it was made worse by food.

Occasionally patients presented low grade fever for which no other cause but hookworm could be found. About half of the patients were tender over the upper abdomen, the tenderness being diffuse rather than localized. Hyperperistalsis on physical examination was the rule.

In contrast to the anemia described in chronic hookworm disease, the red blood cell counts and hemoglobin estimations were normal in all of our patients with but 3 exceptions. The latter were heavily infested and required morphine for relief of their abdominal distress. Of these, 2 had 11 grams of hemoglobin, the third, 13 grams.

About half of the patients had white blood cell counts of over 10,000, the average being about 15,000. The highest leukocyte count recorded was 41,000 in a patient with 70 per cent eosinophilia. Of the 68 individuals in whom differential white blood cell counts were obtained, 8 revealed less than 10 per cent eosinophiles. Thirty patients presented 11–30 per cent eosinophilia and the remaining 30, more than 30 per cent. The highest was 80 per cent recorded in a patient with 25,000 leukocytes. It was our impression that the eosinophiles

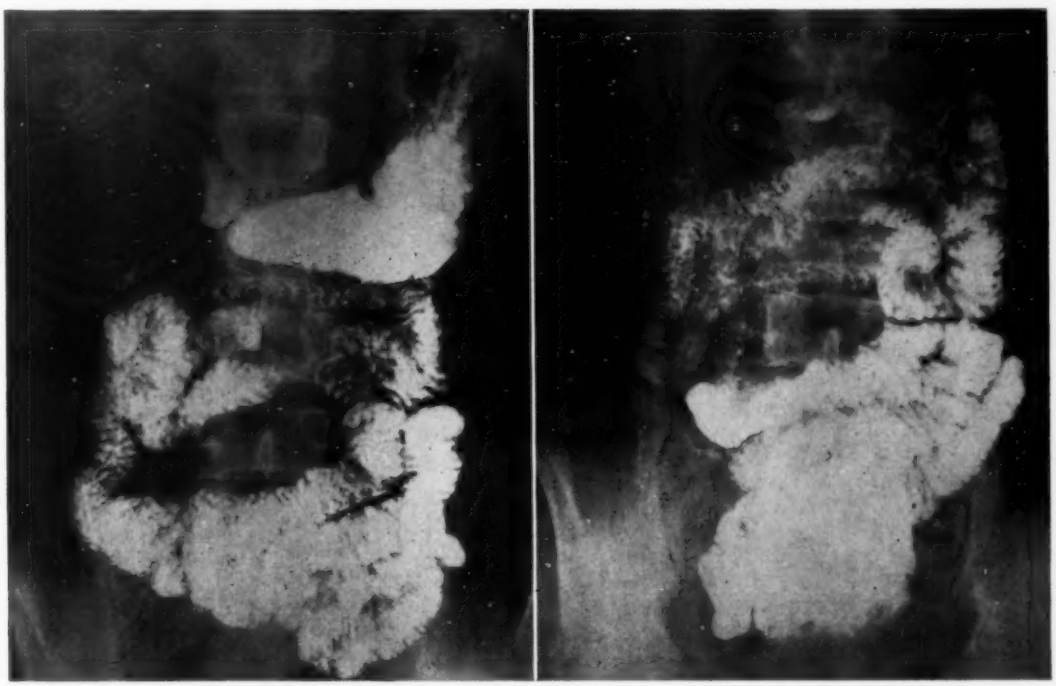

Fig. 3. Normal small intestine. Roentgenograms obtained at one-half and one and one-half hour intervals after distilled water and barium mixture taken by mouth. The barium stream is continuous. The caliber of the lumen is even and the mucosal folds are normal in size and distribution.

in the blood often varied directly with the severity of the clinical findings and the roentgen abnormalities. Usually the eosinophilia decreased as the patient improved.

The following case is reported because it demonstrates the classical sequence of events in hookworm disease. It is the earliest proved case in our experience.

CASE REPORT

On October 27, 1944, the patient, aged twenty-five, crawled under a mobile crane where he worked for about an hour while lying on his back. His shirt pulled out of his trousers exposing his skin to the ground. The patient's back was also exposed by a hole in his shirt. In about one hour he noticed itching. The following day a rash appeared in the skin areas exposed to the soil which lasted for three days.

Four days later, on October 31, the patient developed a cough which disappeared spontaneously in twelve days.

On November 12, sixteen days after the original exposure, he first noticed post-prandial fullness and began to vomit. Cramping abdominal pains also appeared which were made worse by eating. Four days later, on November 16, diarrhea was noted for the first time.

The patient was admitted to the hospital complaining of cramps and diarrhea on November 27, thirty-one days after his exposure. He was well nourished but exhausted. Mild upper abdominal tenderness was the only noteworthy clinical finding. Captain Arthur Rogers, the patient's ward physician, made the diagnosis of hookworm disease from the history alone. His opinion was verified by the hookworm ova found in saline suspensions of the stool obtained twenty-four hours later. At that time the patient's white blood cell count was 13,000 with 66 per cent eosinophiles; hemoglobin was 16.2 grams.

The patient was treated with tetrachlorethylene following which *Ankylostoma duodenale* and *Necator americanus* were identified in the stool. He made an uneventful recovery.

ROENTGEN EXAMINATION

Roentgen Technique. The gastrointestinal studies were done in the morning, the patient having fasted after midnight. Five ounces of barium suspended in 5 ounces of distilled water were used routinely. Roentgenoscopic observations were made in the erect and horizontal positions following which the patient was examined at thirty to forty-five minute intervals, depending upon the findings. Roentgenograms were obtained routinely every half hour for the first two hours and every hour subsequently. In most instances the examinations were completed at the end of three hours.

Roentgen Observations before Treatment. Sixty per cent of the patients with hookworm infestation revealed gastrointestinal abnormalities on roentgen examination. As a rule, the changes were proportional to the severity of the patient's illness. Individuals with mild infestations showed few abnormalities, if any, whereas those with definite distress showed striking changes.

The esophagus was usually normal in patients with ankylostomiasis. Aerophagia and phrenospasm were noted but their incidence was not unusual. Esophageal irritability was never observed in this series.

The stomach was also essentially negative. Exaggerated rugal folds and increased tone were seen occasionally. Gastric emptying was usually normal, or, in rare instances, slightly delayed.

The duodenal bulb was regularly normal. Occasionally, in the seriously ill, it was irritable but it was rarely tender and spastic. In some the mucosal folds seemed prominent but the change was never striking.

The findings were different in the third and fourth portions of the duodenum where marked abnormalities were common in the seriously ill. Increased tone manifest by narrowing of its lumen, and irritability were the rule. They revealed mucosal distortions which varied with the severity of the infestation. Appearing normal in patients with few symptoms, the folds became increasingly thick and distorted as the disease progressed. In many they were spaced irregularly and showed noteworthy variations in size and shape (Fig. 4).

Occasionally the distal duodenum seemed to lose its tone completely. Momentary periods of dilatation were noted at which

Fig. 4. Hookworm disease. Roentgenograms obtained one hour and two and one-half hours after barium meal taken orally. There is considerable delayed motility and duodenal dilatation in *A*. The mucosal pattern is distinctly abnormal. *B* reveals diffuse irritability of the small intestine with long areas of peristaltic contraction and segmentation. Chief complaints were nausea, vomiting, and severe cramps for six weeks. White blood cell count 40,000, with eosinophiles 70 per cent. (Patient was raised in Nebraska.)

time the third and fourth portions of the duodenum ballooned out and appeared sausage shaped. This was a transient phenomenon which was followed promptly by the hypertonic pattern. The change was unpredictable and occurred more often in the jejunum.

Reverse peristalsis was rarely observed in this portion of the small intestine.

Jejunal tenderness was the earliest manifestation of hookworm disease. It was almost always present and was elicited with ease by direct pressure under roentgenoscopic guidance. It occurred with enough regularity to suggest the clinical diagnosis in patients with minor roentgen findings. Whereas the distal duodenum and distal jejunum were often tender also, the area of maximum discomfort was confined usually to the proximal half of the jejunum.

Narrowing of the intestinal lumen and mucosal distortion characterized the roentgen findings. The tone varied directly with the severity of the clinical findings, the lumen approaching one-half to one-third its normal dimensions. Often normal in asymptomatic individuals, the intestine appeared increasingly irritable and intolerant of the barium as the complaints progressed (Fig. 5). With progression these changes involved more and more of the intestine until, in the seriously ill, the entire jejunum and portions of the ileum were involved. Shortening and narrowing of the lumen of the small intestine were also noteworthy in well developed infestations (Fig. 6).

Roentgenoscopically, both segmental and peristaltic contractions were increased in intensity. The normal gentle sway of the small intestine was often replaced by active pendulum movements which were "accordion like" and seen with ease. In rare instances a "cog-wheel" appearance was ob-

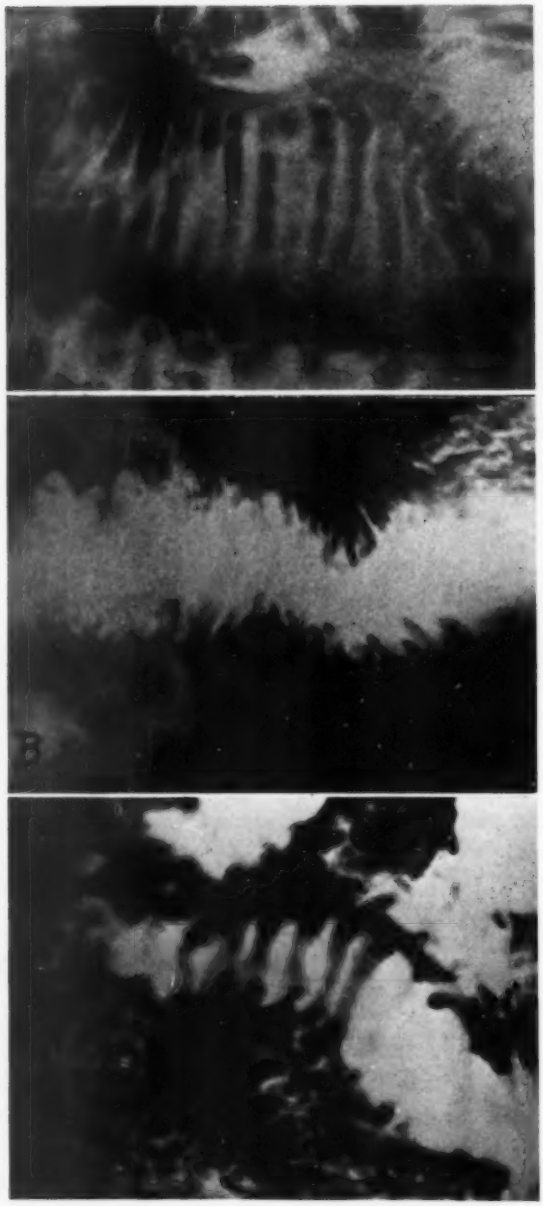

Fig. 5. Hookworm disease. Close-up reproductions of the proximal jejunum taken from the small intestinal studies of 3 patients with hookworm disease. The mucosal folds in *A* are wider and higher than normal; in *B* they are irregularly spaced and point irregularly in all directions; *C* reveals much thicker mucosal folds which are widely separated from each other in one segment.

served roentgenographically which was probably an actual record of a segmental contraction recorded while the film was being exposed (Fig. 7).

Peristalsis was vigorous and rapid. The segments of contracted intestine along the path of the propelling peristaltic waves were narrower and longer than those seen in healthy individuals. The intestine seemed constantly active and unable to relax. Occasionally transient periods of marked relaxation were noted when the jejunum appeared atonic and ballooned out, an appearance described above in the distal duodenum (Fig. 8). Here, too, inhibition of intestinal tone was momentary and was followed immediately by active contractions.

The mucosal folds of the jejunum revealed striking variations. Normally 1 to 2 mm. in width and about the same distance apart, the valvulae conniventes in well developed hookworm disease were two or three times as wide and spaced irregularly apart up to 5 or 7 mm. The folds appeared thick and irregular rather than slender and neat (Fig. 5, 9 and 10). The ease and speed with which their form and direction changed made one confident they were manifestations of an irritable muscularis mucosae rather than organic infiltrations of the mucous membrane (Fig. 14). Also noteworthy were their uneven increase in height and the irregular manner in which they dipped into the column of barium. Instead of small groups of mucosal folds lying parallel there were areas where neighboring folds pointed irregularly in all directions (Fig. 5). The result was anything but the continuous even barium shadow usually seen roentgenographically in the normal jejunum (Fig. 3).

The ileum usually revealed nothing abnormal. About half of the patients in this group showed increased ileal tone (Fig. 9 and 11). In approximately 40 per cent, the barium transit time was slow, being over three hours. Ileal stasis with marked segmentation and bolus formation were not the rule but were not uncommon.

Of particular interest were the mucosal folds in the ileum. Normally low, 1 or 2 mm. high, and widely separated, they were occasionally prominent and closely aligned

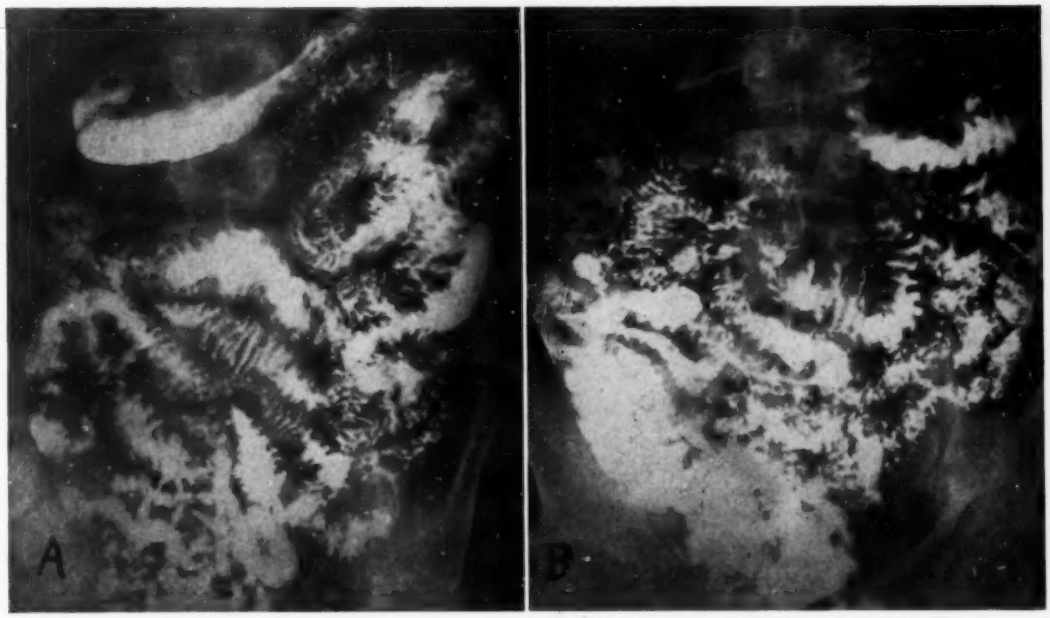

Fig. 6. Hookworm disease. Roentgenograms obtained fifteen minutes (*A*) and one hour (*B*) after oral administration of barium. The entire small intestine is irritable and seems unable to relax. The mucosal folds are wide, irregular in height, and unevenly spaced. Chief complaint was post-prandial epigastric distress for three weeks. White blood cell count 18,000, with 48 per cent eosinophiles. (Patient was raised in New York State.)

in hookworm disease (Fig. 12). In this the mucosal pattern of the terminal ileum mimicked that of the normal jejunum. When present, it was invariably associated with marked jejunal changes.

Roentgen Observations after Treatment. Twenty-eight patients were examined from one to four times after treatment. A few were studied two to four weeks after treatment; many more were re-examined at the end of two to six months.

Two patients with jejunal tenderness but no roentgen abnormalities were re-examined three and ten weeks after treatment. The gastrointestinal tracts were normal and the tenderness gone in both. Neither was very ill when first seen, however.

Fourteen patients with moderately severe clinical complaints and moderate roentgen changes were re-examined one to three months after therapy. In 3 the gastrointestinal tract returned to normal in one to two months (Fig. 10). Six patients revealed roentgen evidence of improvement one to three months after treatment. Three were unchanged after one to three months

Fig. 7. Hookworm disease. "Cog-wheel" jejunal pattern. This was occasionally seen and probably represents a record of a rhythmic segmental contraction obtained during the time the film was being exposed. One might consider it a kymogram of a pendulum movement.

FIG. 8. Hookworm disease. Roentgenogram obtained one hour after barium by mouth. Note dilated jejunal loop with flat mucosal folds. Chief complaint was abdominal cramps. Hemoglobin 13 grams; 60 per cent eosinophiles. (Patient was raised in Iowa.)

and 2 were definitely worse three months later. Clinically all but the last 2 were considerably improved or entirely well at the time the follow-up study was done.

Twelve seriously ill patients were reexamined three to six months after completing an adequate therapeutic course. Five showed marked improvement in the roentgen appearance of the intestine in three months. Of the latter, one was well clinically, and the second was improved but not symptom free. In 3, the intestinal distortion was worse four to six months after treatment. One of the latter was much improved clinically, one was moderately improved, and the third unchanged. In such instances repeated stool examinations occasionally revealed ova even though they had been negative following the first therapeutic course.

FIG. 9. Hookworm disease. Same patient as described in Figure 4. *A*, original study made two and one-half hours after barium by mouth. *B*, re-examination five months later at same two and one-half hour interval. Patient clinically well at this time, but stools still positive. Note the more adequate relaxation of the small intestine. The mucosal folds are still long, thick, and irregularly spaced.

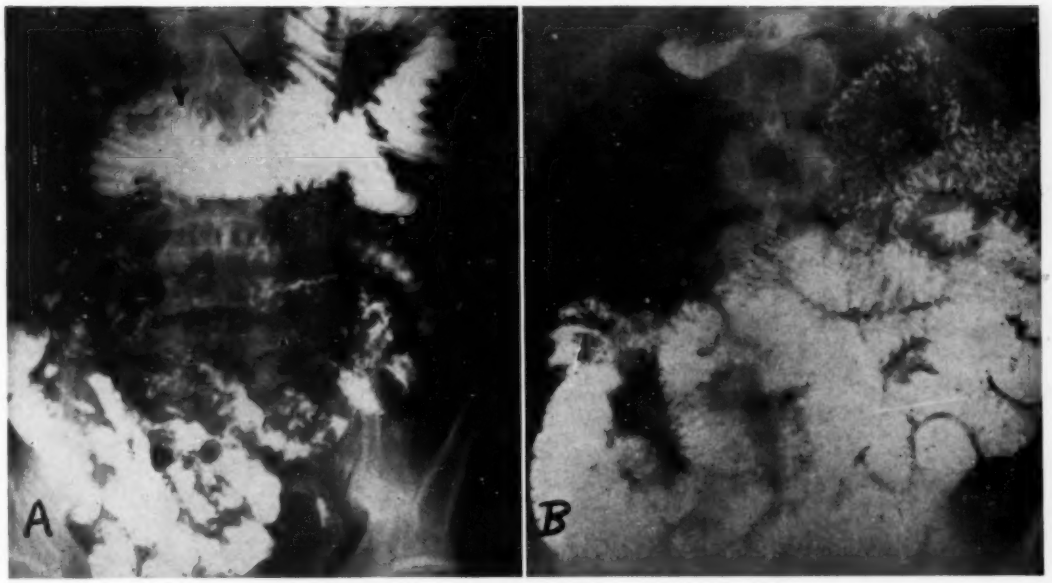

Fig. 10. Hookworm disease. Original small intestinal study in *A*. Roentgenogram obtained one and one-half hours after ingested barium meal. Note dilated jejunal loops with highly accentuated mucosal folds. The distal jejunum and proximal ileum reveal marked contraction, an appearance which could be attributed to failure of relaxation. Chief complaints were generalized abdominal pain, nausea, and vomiting of four weeks' duration. White blood cell count, 7,600, with 21 per cent eosinophiles. *B*, four months later, small intestinal pattern essentially normal at same one and one-half hour interval. Patient well except for slight abdominal tenderness. (Patient raised in New York State.)

With improvement the jejunal tenderness diminished and then disappeared. Whereas the intestinal pattern often remained abnormal, it seemed less irritable and spastic. Motility, too, tended to return to normal, and in some actually became rapid (Fig. 13). The greatest delay in improvement was noted in the mucosal folds, which often remained distorted for months after patients were apparently cured.

Occasionally, following treatment, the intestinal pattern changed abruptly from the normal to abnormal. Occurring one to one and a half hours after the barium meal was ingested, the change was characterized by hyperperistalsis, excess segmental contraction and mucosal distortion, all manifestations of failure of relaxation. The evidence suggested that the sudden change we observed might be due to derangement of reflexes which normally controlled intestinal activity. Perhaps fatigue of a previously damaged intramural nervous system was responsible for the abrupt variations described above.

DISCUSSION

Complete gastrointestinal studies were obtained in 10 healthy members of our command as soon as we arrived in India (Fig. 3). Anticipating nutritional deficiencies and intestinal diseases, we did this to have controls available for future reference. About sixteen months later these men were re-examined clinically and roentgenologically; no changes were found. Viewed in the light of these control studies, it seemed reasonable to conclude that the changes we saw in hookworm disease were not due to diet alone.

Krause and Crilly[5] attributed the intestinal distortions to "certain dietary factors," feeling that neither the actual presence of worms nor anemia was responsible for the changes. Golden, discussing their paper, suggested that the hookworms

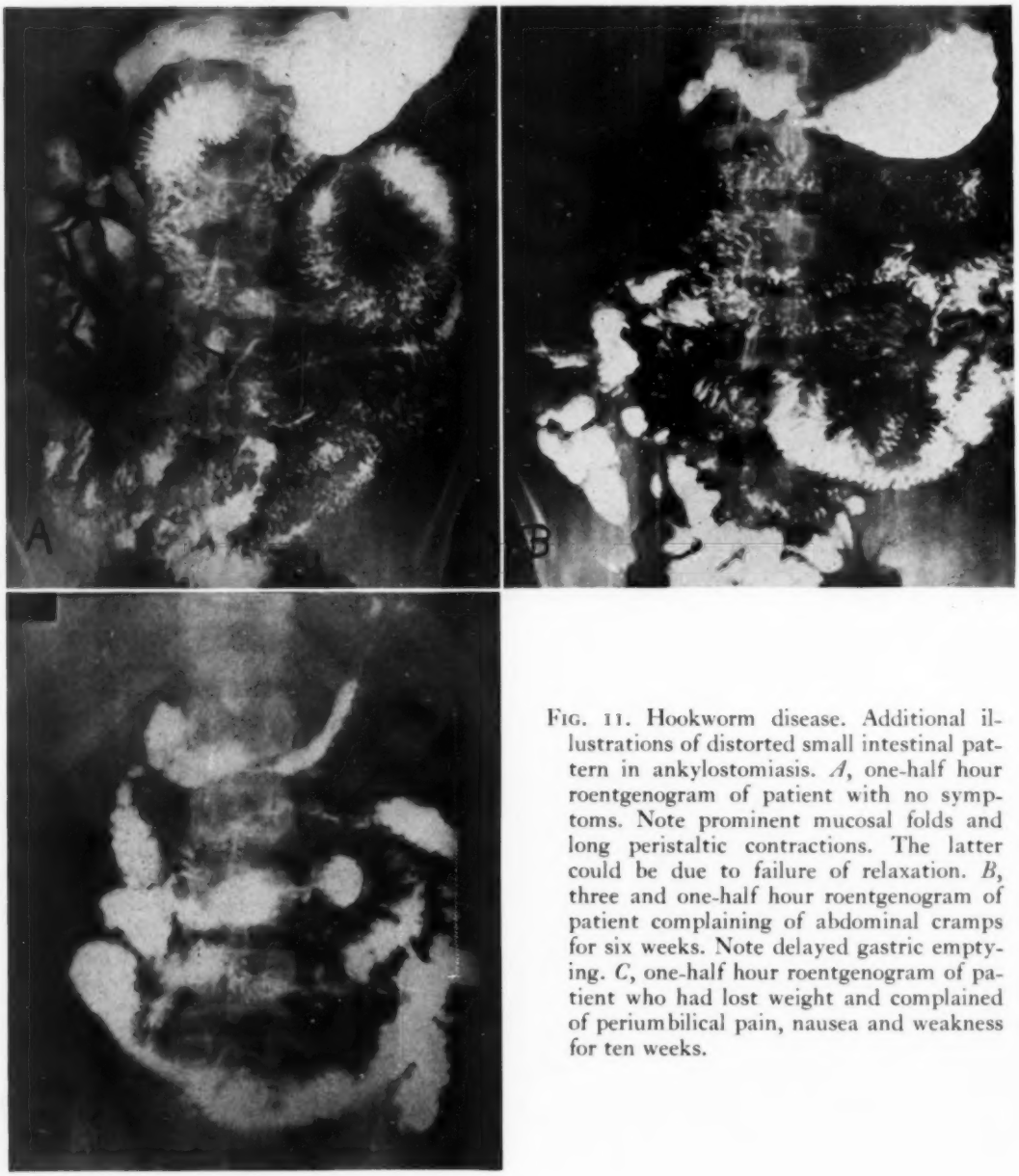

FIG. 11. Hookworm disease. Additional illustrations of distorted small intestinal pattern in ankylostomiasis. *A*, one-half hour roentgenogram of patient with no symptoms. Note prominent mucosal folds and long peristaltic contractions. The latter could be due to failure of relaxation. *B*, three and one-half hour roentgenogram of patient complaining of abdominal cramps for six weeks. Note delayed gastric emptying. *C*, one-half hour roentgenogram of patient who had lost weight and complained of periumbilical pain, nausea and weakness for ten weeks.

themselves, as well as nutritional disturbances, might have been the cause.

Many of our patients were below their normal weight when we first saw them. They revealed no clinical evidence of malnutrition or anemia; the former could have been present but not recognized. The same could have been true of hypoproteinemia which we did not exclude because of conditions beyond our control. Admitting all these factors (anemia, nutritional deficiencies, hypoproteinemia, the actual presence of the hookworms) to be important in the production of the intestinal changes seen before treatment, it was difficult to explain why the distorted roentgen pattern persisted after treatment in many patients who were well clinically.

Reports of cases of hookworm disease found in a limited review of the literature

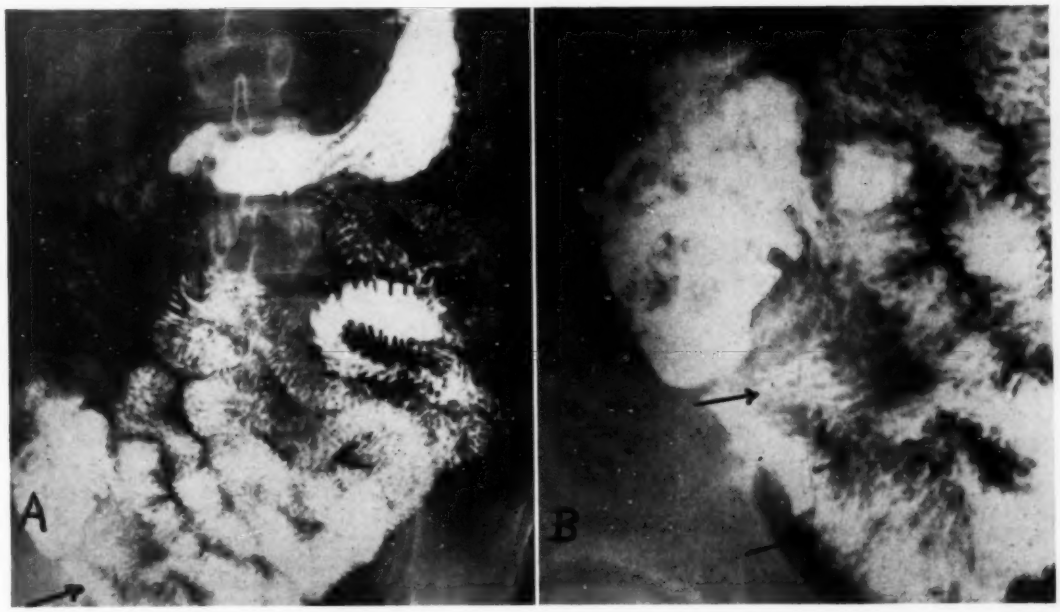

FIG. 12. Hookworm disease. Roentgenogram obtained one and one-half hours after oral ingestion of barium meal. Note continuous stream of barium in *A*. The mucosal folds are clearly visualized throughout the ileum. Enlargement of ileocecal portion of *A* seen in *B* reveals the prominent and wide mucosal folds to better advantage.

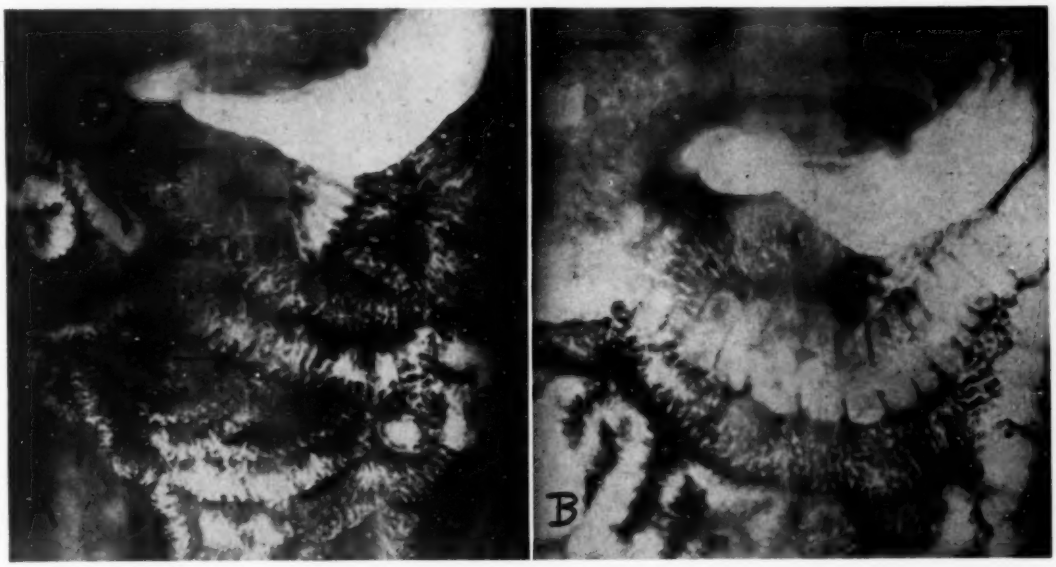

FIG. 13. Hookworm disease. *A*, original oral barium meal study. Roentgenogram obtained one-half hour after barium meal. The barium stream is continuous but the bowel is hypertonic, narrow, and shortened. The mucosal folds are coarse and irregular in height, width, and spacing. Chief complaints were nausea, postprandial abdominal cramps, and right upper quadrant pain of ten weeks' duration. White blood cell count 6,700, with 50 per cent eosinophiles; hemoglobin 14.5 gm. *B*, three months later, roentgenogram taken at same one-half hour interval reveals rapid transit time with barium in splenic flexure. The small intestine is less hypertonic, but still abnormal. (Patient was raised in West Virginia.)

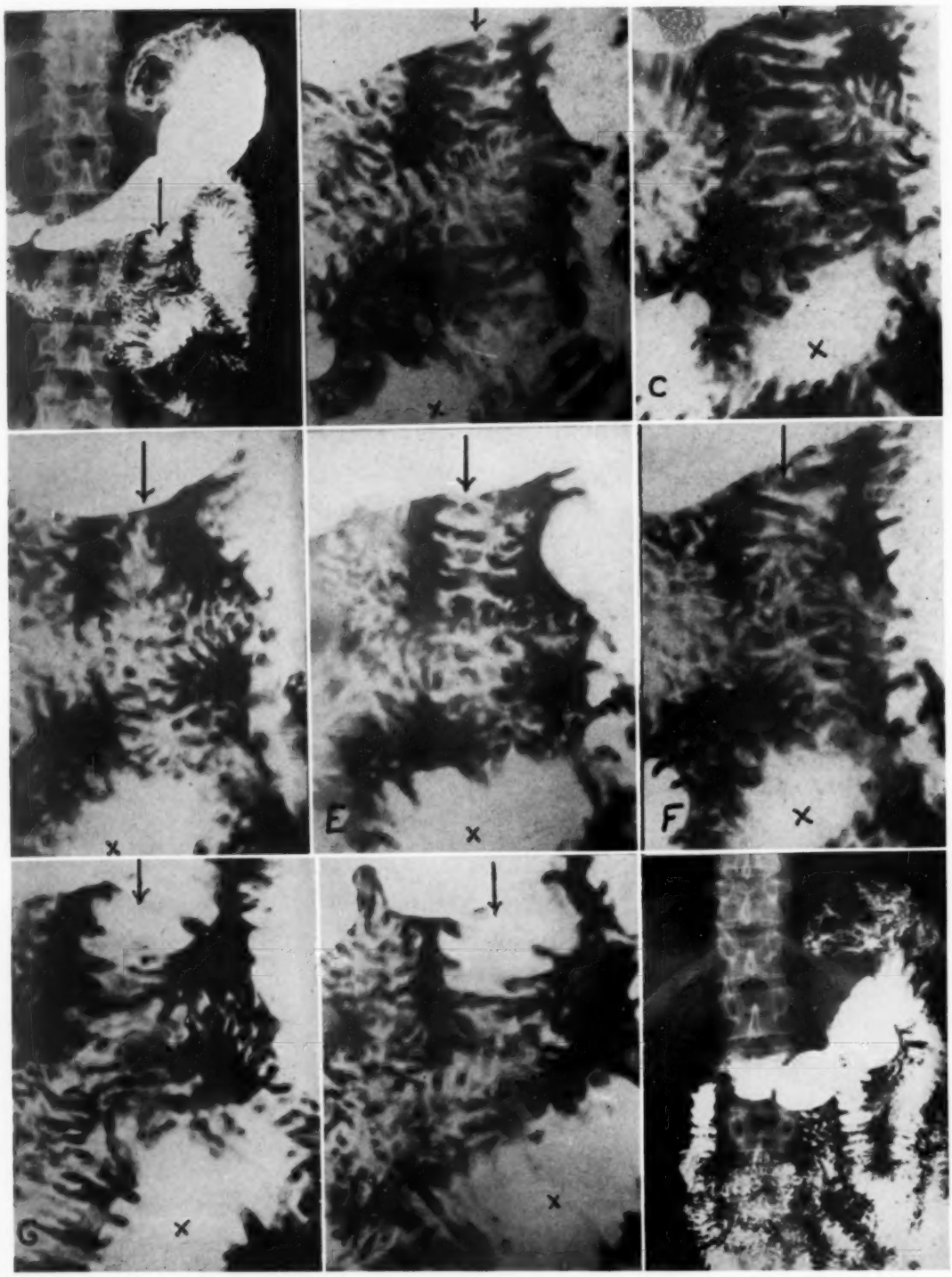

FIG. 14. Hookworm disease. Series of exposures made to demonstrate the speed with which the mucosal pattern can change. Roentgenograms were obtained at about ten to fifteen second intervals. *A* is a reproduction of one of this series of 14 by 17 inch exposures shown to orient the reader. The one loop of jejunum chosen to demonstrate the mucosal activity is indicated by the arrow. The subsequent reproductions are close-up

say little about the histopathlogical characteristics of the wall of the small intestine. Mention was made of "hemorrhage, eosinophilic infiltration, and edema," but nothing definite was gathered concerning the thickness of the intestine or the condition of its intramural nervous system.

Golden,[2] reviewing the physiology of the small intestine, called attention to the importance of the latter. He commented upon the delicate balance that exists between the sympathetic and parasympathetic nervous systems. He presented numerous illustrations of "disordered motor function" among which he included the distorted pattern of nutritional disturbances. Of unusual interest and importance were his comments about the pathology of the intramural nervous system and the "vacuolization of nerve cells in both myenteric and submucosal plexuses" demonstrated with special stains in a patient with nontropical sprue. Of equal significance were Ingelfinger and Moss's[4] observations in sprue where they noted that the intramural nervous apparatus was unable to liberate active acetylcholine and that the injection of acetylcholine produced intestinal movements.

It was our impression that the mucosal changes seen in hookworm disease were in the main due to an abnormal intramural nervous system. We felt that disturbances in reflex arcs rather than actual thickening of the wall of the intestine were responsible for the distorted mucosal pattern. It was found difficult to picture an indurated intestine changing its mucosal appearance and lumen with the speed that characterized the small intestine in this study (Fig. 14).

The roentgen observations tend to support this postulate. If the intramural nervous system were damaged one could understand why distorted mucosal patterns persisted after the hookworms were destroyed by vermifuges. Conversely, if the intramural nervous system remained intact or but slightly damaged it would explain why 40 per cent of patients with hookworm disease revealed no roentgen evidence of distorted mucosal folds. The latter observation lends further support to the idea that the presence of hookworms alone is not responsible for the mucosal changes. Finally, it would explain why the disordered motor function pattern differed from patient to patient, for if the degree of involvement of the intramural nervous system varied it would seem proper for the intestinal pattern to vary.

What damaged the intramural nervous system, if indeed it was damaged, remained a moot problem. We believe it highly possible that the hook-like teeth of the parasites were to blame. Cutting into the mucous membrane at the site of their embedded buccal capsule they might readily have interfered with the elaborate network of nerve cells and fibers which extend to every portion of the intestine from the subserosal, Auerbach's, the deep muscular, and Meissner's plexuses. That toxins, too, might have played a part cannot be denied; the fact that an immunity to hookworm disease in dogs has been produced experimentally implies that this is a possibility for it suggests the presence of an endotoxin. The latter seems unlikely, however.

SUMMARY

1. Over 125 American troops with proved ankylostomiasis were examined roentgenologically for gastrointestinal changes.

2. Approximately 60 per cent revealed roentgen abnormalities in the small intestine.

3. Changes in the small intestine were

enlargements of this one loop which are arranged in the order in which they were taken. The mucosal folds are not static. From roentgenogram to roentgenogram definite changes in height, width, and spacing occur which could not happen were the mucosa and submucosa thickened enough to have caused the distortion. Similar intestinal activity can be observed at *X* which is a lower jejunal loop. The film in the lower right hand corner was taken immediately after the series of exposures was completed.

noted within one month after exposure to the parasites.

4. Whereas the intestinal abnormalities demonstrable by roentgen methods appeared first in the proximal jejunum, they spread into the distal duodenum, distal jejunum, and throughout the ileum.

5. The changes were those of "disordered motor function," characterized by excessive peristaltic and segmental contractions with distortion of the mucosal pattern.

6. Improvement in the roentgen manifestations of the disease occurred early in some cases and in many others was delayed. Not infrequently the abnormal changes persisted for months after the patient was well clinically.

7. Causes for the intestinal changes in hookworm disease are discussed and the possibility of their being in part due to a damaged intramural nervous system is postulated.

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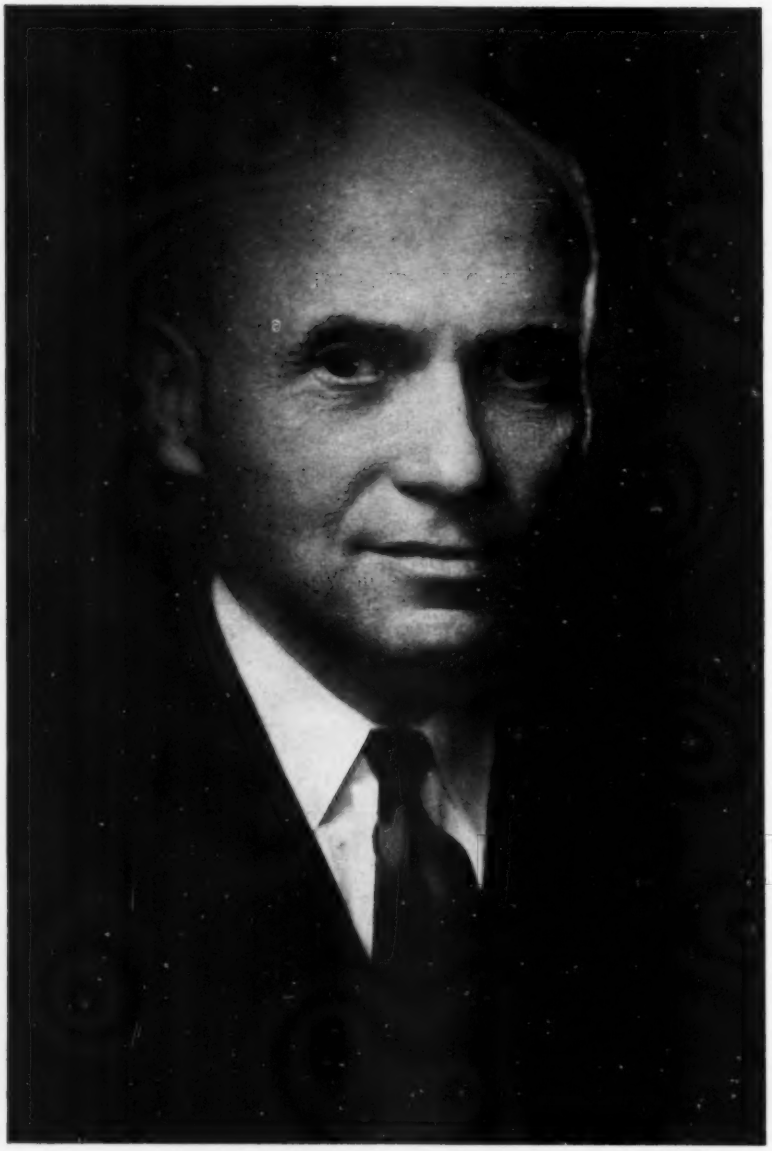

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ROSS GOLDEN

President of the American Roentgen Ray Society 1945–1946

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Forty-fifth Annual Meeting: 1945, canceled.

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Representatives on American Board of Radiology: Douglas Quick, New York, N. Y., B. P. Widmann, Philadelphia, Pa., F. W. O'Brien, Boston, Mass.

Twenty-eighth Annual Meeting: 1945, canceled

EDITORIAL

FIFTIETH ANNIVERSARY OF THE DISCOVERY OF THE ROENTGEN RAY

SCIENCE dawned though late upon the earth and the science of roentgenology much, much later. The steady sure progress in human endeavor was never better exemplified than in the story of the forefathers of Röntgen; each in his turn added a bit of knowledge which ultimately resulted in the discovery of the roentgen ray, a discovery of unparalleled fruitfulness in the advancement of benefit to the human race, which had led us steadily but surely up "the steep ascent from the unknown to the known." Within the span of fifty years we have progressed from a faint flicker of the cathode ray upon the fluorescent screen in Röntgen's laboratory in Würzburg to the fall of the atomic bomb upon Hiroshima. Between these two events there has emerged from the careful thought and experimentation of many minds and hands over the, world a well ordered road map of experience not only in the diagnostic and therapeutic aspect of roentgenology but also in the use of the roentgen ray in many other fields.

We are too close to the events which accompanied the development of the atomic bomb to have a full realization and appreciation of its portent. However, it is well to survey some of the tremendous advances that have been made not only in medicine but also in chemistry and physics since the discovery of the roentgen ray. Perhaps no single episode which has resulted from a scientific effort has so influenced the progress of the human race. By its use we have opened a new era not only in the diagnostic but also in the therapeutic approach to disease.

The employment of the roentgen ray in its earliest stages gave us a new conception of the skeletal structures and made possible the diagnosis of inflammatory diseases and tumors which involve this system, and in these later years the roentgen ray has been used in the determination of bone dyscrasias which result from endocrine and metabolic disturbances. Its employment in the normal physiology of growth and development is comparatively recent and is of untold importance. Without the roentgen ray the whole recent advance in neurological surgery would not have been possible. As an ancillary in the diagnosis of tumors and diseases of the brain and spinal cord a new chapter in surgery has been written. The great advances that have been made in the physiology of the respiratory system as well as in the diagnosis of diseases of the respiratory system are almost incredible. A formidable diagnostic aid has been added to the stethoscope and one might say has almost replaced it as a diagnostic instrument.

As a result of the peculiar fitness of the roentgen ray for the early diagnosis of tuberculosis we have brought this disease almost within the limits of control, though the roentgen ray as a method of study of diseases of the chest was not generally accepted until 1912. Without the roentgen ray the enormous progress that has been made in thoracic surgery would have been delayed years, and yet within the present generation by its use the surgical approach not only to diseases of the respiratory system itself but to the circulatory system as well has been made possible.

The steady advances in our knowledge of the normal physiology of the gastrointestinal tract as well as its pathology have been made possible by the use of the roentgen ray. With its employment in diseases

of the genitourinary tract the diagnosis of urological conditions has almost approached an exact science.

Shortly after the discovery of the roentgen ray the possibility of using it therapeutically became evident and within a comparatively short time following the announcement of the discovery, superficial skin lesions and cancers of the skin were treated with roentgen radiation. Since those early days we have seen a steady progress in the use of the roentgen ray in the treatment of various diseases, but particularly neoplastic disease. This progress has been a sure one and has been made possible by the continuous improvement in the construction of tubes and mechanical devices for measuring the quality of the roentgen radiation administered. No longer do we rely upon inadequate or unsatisfactory equipment in this respect and with the technical advances made in the construction of machines the end in the radiation therapy of tumors is not yet. The advances in the use of the roentgen ray as a therapeutic agent have been so important that we now have specialization in radiotherapy.

There is no branch of medicine which has not benefited by the employment of the roentgen ray. With its use the workers in physics and chemistry have unlocked the wicket gates of nature; they have explored the realm of the unknown and have unraveled many of its secrets and thus have been able to harness additional forces of nature.

The recent experimental work with the roentgen ray has opened an entirely new chapter in atomic energy, the possibilities of which are already being explored. Some hint of the outcome of these explorations is given in a thought-provoking paper on "Utilization of Antibody for the Localization of Metals and Dyes in the Tissues" found elsewhere in this issue.

In the realm of industry we have seen revolutionary changes as the result of the employment of the roentgen ray in the spectral analysis of metals, eliminating to a marked degree the trial and error methods which had hitherto been followed. Such revolutionary changes have also resulted from the roentgenologic examination of the various products of industry during their process of manufacture and after their completion.

The whole history of the roentgen ray from the day of its discovery until the present time is one of steady sure progress in every field of scientific endeavor. With this issue of the JOURNAL we commemorate the Fiftieth Anniversary of the discovery of the roentgen ray—one of man's greatest achievements.

SOCIETY PROCEEDINGS, CORRESPONDENCE AND NEWS ITEMS

Items for this section solicited promptly after the events to which they refer.

MEETINGS OF ROENTGEN SOCIETIES*

UNITED STATES OF AMERICA

AMERICAN ROENTGEN RAY SOCIETY
Secretary, Dr. H. Dabney Kerr, University Hospital, Iowa City, Iowa. Annual meeting: 1945, canceled.

AMERICAN COLLEGE OF RADIOLOGY
Secretary, Mac F. Cahal, 540 N. Michigan Ave., Chicago.

SECTION ON RADIOLOGY, AMERICAN MEDICAL ASSOCIATION
Secretary, Dr. U. V. Portmann, Cleveland Clinic, Cleveland, Ohio. Annual meeting: 1945, canceled.

ARKANSAS RADIOLOGICAL SOCIETY
Secretary, Dr. J. S. Wilson, Mack Wilson Hospital, Monticello, Ark. Meets every three months and also at time and place of State Medical Association.

RADIOLOGICAL SOCIETY OF NORTH AMERICA
Secretary, Dr. D. S. Childs, 607 Medical Arts Bldg., Syracuse, N. Y. Annual meeting: 1945, cancelled.

RADIOLOGICAL SECTION, BALTIMORE MEDICAL SOCIETY
Secretary, Dr. Walter L. Kilby, Baltimore. Meets third Tuesday each month, September to May.

SECTION ON RADIOLOGY, CALIFORNIA MEDICAL ASSOCIATION
Secretary, Dr. Gordon G. King, 3700 California St., San Francisco 18, Calif.

RADIOLOGICAL SECTION, CONNECTICUT MEDICAL SOCIETY
Secretary, Dr. Max Climan, 242 Trumbull St., Hartford, Conn. Meets bi-monthly on second Thursday, at place selected by Secretary. Annual meeting in May.

SECTION ON RADIOLOGY, ILLINOIS STATE MEDICAL SOCIETY
Secretary, Dr. H. W. Ackemann, 321 W. State St., Rockford, Ill.

RADIOLOGICAL SECTION, LOS ANGELES COUNTY MEDICAL ASSOCIATION
Secretary, Dr. Roy W. Johnson, 1407 S. Hope St., Los Angeles, Calif. Meets on second Wednesday of each month at the County Society Building.

RADIOLOGICAL SECTION, SOUTHERN MEDICAL ASSOCIATION
Secretary, Dr. Roy G. Giles, Temple, Texas.

BROOKLYN ROENTGEN RAY SOCIETY
Secretary, Dr. Leo Harrington, 880 Ocean Ave., Brooklyn, N.Y. Meets monthly on fourth Tuesday, October to April.

BUFFALO RADIOLOGICAL SOCIETY
Secretary, Dr. Joseph S. Gian-Francheschi, 610 Niagara St., Buffalo, N. Y. Meets second Monday of each month except during summer months.

CHICAGO ROENTGEN SOCIETY
Secretary, Dr. F. H. Squire, 1754 W. Congress St., Chicago 12, Ill. Meets second Thursday of each month October to April inclusive at the Palmer House.

CINCINNATI RADIOLOGICAL SOCIETY
Secretary, Dr. Samuel Brown, 707 Race St., Cincinnati, Ohio. Meets third Tuesday of each month, October to May, inclusive.

CLEVELAND RADIOLOGICAL SOCIETY
Secretary, Dr. Carroll C. Dundon, 2065 Adelbert Road, Cleveland 6, Ohio. Meetings at 6:30 P.M. on fourth Monday of each month from October to April.

DALLAS-FORT WORTH ROENTGEN STUDY CLUB
Secretary, Dr. X. R. Hyde, Medical Arts Bldg., Fort Worth, Texas. Meetings held in Dallas on odd months and in Fort Worth on even months, on third Monday, at 7:30 P.M.

DENVER RADIOLOGICAL CLUB
Secretary, Dr. A. Page Jackson, Jr., 1612 Tremont Place, Denver, Colo. Meets third Friday of each month at Denver Athletic Club.

DETROIT ROENTGEN RAY AND RADIUM SOCIETY
Secretary, Dr. E. R. Witwer, Harper Hospital. Meets monthly on first Thursday from October to May, at Wayne County Medical Society Building.

FLORIDA RADIOLOGICAL SOCIETY
Secretary, Dr. J. F. Pitman, Blanch Hotel Annex, Lake City, Fla. Meetings in May and November.

GEORGIA RADIOLOGICAL SOCIETY
Secretary, Dr. James J. Clark, 478 Peachtree St., Atlanta, Ga. Meets in November and at annual meeting of Medical Association of Georgia in the spring.

RADIOLOGICAL SOCIETY OF KANSAS CITY
Secretary, Dr. Arthur B. Smith, 800 Argyle Bldg., Kansas City, Mo. Meets third Thursday of each month.

ILLINOIS RADIOLOGICAL SOCIETY
Secretary, Dr. Wm. DeHollander, St. John's Hospital, Springfield, Ill. Meets three times a year.

INDIANA ROENTGEN SOCIETY
Secretary, Dr. H. C. Ochsner, Methodist Hospital, Indianapolis. Meets annually second Sunday in May.

IOWA X-RAY CLUB
Secretary, Dr. Arthur W. Erskine, 326 Higley Bldg., Cedar Rapids, Iowa. Luncheon and business meeting during annual session of Iowa State Medical Society. Special meetings by announcement.

KENTUCKY RADIOLOGICAL SOCIETY
Secretary, Dr. W. C. Martin, 321 W. Broadway, Louisville. Meets annually in Louisville on first Saturday in Apr.

LONG ISLAND RADIOLOGICAL SOCIETY
Secretary, Dr. Marcus Wiener, 1430-48th St., Brooklyn, N. Y. Meets Kings County Med. Soc. Bldg. monthly on fourth Thursday, October to May, 8:30 P.M.

LOUISIANA RADIOLOGICAL SOCIETY
Secretary, Dr. J. R. Anderson, 1130 Louisiana Ave., Shreveport. Meets annually during Louisiana State Medical Society Meeting.

MICHIGAN ASSOCIATION OF ROENTGENOLOGISTS
Secretary, Dr. E. M. Shebesta, 1429 David Whitney Bldg., Detroit. Three meetings a year, Fall, Winter, Spring.

MILWAUKEE ROENTGEN RAY SOCIETY
Secretary, Dr. C. A. H. Fortier, 231 W. Wisconsin Ave., Milwaukee, Wis. Meets monthly on second Monday at University Club.

MINNESOTA RADIOLOGICAL SOCIETY
Secretary, Dr. Annette T. Stenstrom, 1218 Medical Arts Bldg., Minneapolis, Minn. One meeting a year at time of Minnesota State Medical Association.

NEBRASKA RADIOLOGICAL SOCIETY
Secretary, Dr. D. A. Dowell, Medical Arts Bldg., Omaha, Nebr. Meets third Wednesday of each month, at 6 P.M. at either Omaha or Lincoln.

NEW ENGLAND ROENTGEN RAY SOCIETY
Secretary, Dr. George Levene, Massachusetts Memorial Hospitals, Boston, Mass. Meets monthly on third Friday, Boston Medical Library.

NEW HAMPSHIRE ROENTGEN RAY SOCIETY
Secretary, Dr. Richard C. Batt, Berlin, N. H. Four meetings a year.

RADIOLOGICAL SOCIETY OF NEW JERSEY
Secretary, Dr. H. R. Brindle, 501 Grand Ave., Asbury Pk. Meets annually at time and place of State Medical Society. Mid-year meetings at place chosen by president.

NEW YORK ROENTGEN SOCIETY
Secretary, Dr. Ramsay Spillman, 115 East 61st St., New York City. Meets monthly on third Monday, New York Academy of Medicine, at 8:30 P.M.

NORTH CAROLINA ROENTGEN RAY SOCIETY
Secretary, Dr. Major Fleming, Rocky Mount, N. C. An-

* Secretaries of Societies not here listed are requested to send the necessary information to the Editor.

nual meeting at time and place of State Medical Society. Mid-year scientific meeting at place designated.

North Dakota Radiological Society
Secretary, Dr. L. A. Nash, St. John's Hospital, Fargo. Meetings held by announcement.

Central New York Roentgen Ray Society
Secretary, Dr. C. F. Potter, 820 S. Crouse Ave., Syracuse. Three meetings a year. January, May, November.

Ohio Radiological Society
Secretary, Dr. Henry Snow, 1061 Reibold Bldg., Dayton, Ohio. Meets during annual meeting of Ohio State Medical Association.

Pacific Roentgen Society
Secretary, Dr. L. H. Garland, 450 Sutter St., San Francisco, Calif. Meets annually, during meeting of California Medical Association.

Pennsylvania Radiological Society
Secretary, Dr. L. E. Wurster, 416 Pine St., Williamsport.

Philadelphia Roentgen Ray Society
Secretary, Dr. C. L. Stewart, Jefferson Hospital, Meetings first Thursday of each month, October to May, at at 8:00 P.M., in Thomson Hall, College of Physicians, 21 S. 22d St.

Pittsburgh Roentgen Society
Secretary, Dr. L. M. J. Freedman, 4800 Friendship Ave. Meets 6:30 P.M. at The Ruskin on second Wednesday, each month, October to May inclusive.

Rochester Roentgen Ray Society, Rochester, N. Y.
Secretary, Dr. Murray P. George, Strong Memorial Hospital. Meets monthly on third Monday from October to May, inclusive, 8 P.M. at Strong Memorial Hospital.

Rocky Mountain Radiological Society
Secretary Dr. A.M. Popma, 220 N. First St., Boise, Idaho.

St. Louis Society of Radiologists
Secretary, Dr. Edwin C. Ernst, Beaumont Medical Building, St. Louis, Mo. Meets fourth Wednesday of each month, except June, July, August, and September, at a place designated by the president.

San Diego Roentgen Society
Secretary, Dr. Henry L. Jaffe, Naval Hospital, Balboa Park, San Diego, Calif. Meets monthly on first Wednesday at dinner.

San Francisco Radiological Society
Secretary, Dr. Carlton L. Ould, University of California Hospital, San Francisco 22. Meets monthly on the third Thursday at 7:45 P.M., first six months of the year at Lane Hall, Stanford University Hospital, and second six months at Toland Hall, University of California Hospital.

Shreveport Radiological Club
Secretary, Dr. R. W. Cooper, Charity Hospital, Shreveport, La. Meets monthly on third Wednesday, at 7:30 P.M., September to May inclusive.

South Carolina X-Ray Society
Secretary, Dr. T. A. Pitts, Baptist Hospital, Columbia, S. C. Meets in Charleston on first Thursday in November, also at the time and place of South Carolina State Medical Association.

Tennessee Radiological Society
Secretary, Dr. J. M. Frère, 707 Walnut St., Chattanooga, Tenn. Meets annually at the time and place of the Tennessee State Medical Association.

Texas Radiological Society
Secretary, Dr. R. P. O'Bannon, 650 Fifth Ave., Fort Worth 4, Texas. Next meeting, Dallas, Texas, Monday, January 14, 1946.

University of Michigan Department of Roentgenology Staff Meeting
Meets each Monday evening from September to June, at 7 P.M. at University Hospital.

University of Wisconsin Radiological Conference
Secretary, Dr. E. A. Pohle, 1300 University Ave., Madison, Wis. Meets every Thursday from 4:00–5:00 P.M., Room 301, Service Memorial Institute.

Virginia Radiological Society
Secretary, Dr. E. L. Flanagan, 116 E. Franklin St., Richmond, Va. Meets annually in October.

Washington State Radiological Society
Secretary, Dr. Thomas Carlile, 1115 Terry St., Seattle. Meets fourth Monday each month, October through May, College Club, Seattle.

X-ray Study Club of San Francisco
Secretary, Dr. J. M. Robinson, University of California Hospital. Meets monthly, third Thursday evening.

Cuba

Sociedad de Radiología y Fisioterapia de Cuba
President, Dr. J. Manuel Viamonte, Hospital Mercedes, Habana, Cuba. Meets monthly in Habana.

British Empire

British Institute of Radiology Incorporated with the Röntgen Society
Medical Members' meeting held monthly on third Friday at 2:30 P.M. and Ordinary Meeting at same time on following Saturday, October to May, 32 Welbeck St., London, W.1.

Section of Radiology of the Royal Society of Medicine (Confined to Medical Members)
Meets on the third Friday of each month at 4:45 P.M. at the Royal Society of Medicine 1, Wimpole St., London, W. 1.

Faculty of Radiologists
Secretary, Dr. M. H. Jupe, 32 Welbeck St., London, W. 1 England.

Section of Radiology and Medical Electricity, Australasian Medical Congress
Secretary, Dr H. M. Cutler, 139 Macquarie St., Sydney, New South Wales.

Radiological Section of the Victorian Branch of the British Medical Association
Secretary, Dr. Keith Hallam, St. George's Hospital, K.E.W., Melbourne, E. 4, Victoria, Australia. Meets monthly from March to November inclusive.

Canadian Association of Radiologists
Secretary, Dr. J. W. McKay, 1620 Cedar Ave., Montreal, P. Q.

Section of Radiology, Canadian Medical Association
Secretary, Dr. C. M. Jones, Inglis St., Ext. Halifax, N. S.

Radiological Section, New Zealand British Medical Association
Secretary, Dr. Colin Anderson, Invercargill, New Zealand. Meets annually.

South America

Sociedad Argentina de Radiologia
Secretary, Dr. Guido Gotta, Buenos Aires, Argentina. Meetings are held monthly.

Sociedad Peruana de Radiologia
Secretary, Dr. Victor Giannoni, Apartado, 2306, Lima, Peru. Meetings held monthly except during January, February and March, at the Asociación Médica Peruana "Daniel A. Carrión, Villalta 218, Lima.

Continental Europe

Sociedad Espanola de Radiologia y Electrologia
Secretary, Dr. J. Martin-Crespo, Fuencarral, 7. Madrid, Spain. Meets monthly in Madrid.

Société Suisse de Radiologie (Schweizerische Röntgen-Gesellschaft)
Secretary for French language, Dr. Babaiantz, Geneva. *Secretary* for German language, Dr. Max Hopf, Effingerstrasse 49, Bern. Meets annually in different cities.

Societatea Romana de Radiologie si Electrologie
Secretary, Dr. Oscar Meller, Str. Banul Mărăcine, 30, S. I., Bucuresti, Roumania. Meets second Monday in every month with the exception of July and August.

All-Russian Roentgen Ray Association, Leningrad: USSR in the State Institute of Roentgenology and Radiology, 6 Roentgen St.
Secretaries, Drs. S. A. Reinberg and S. G. Simonson. Meets annually.

Leningrad Roentgen Ray Society
Secretaries, Drs. S. G. Simonson and G. A. Gusterin. Meets monthly, first Monday at 8 o'clock, State Institute of Roentgenology and Radiology, Leningrad.

Moscow Roentgen Ray Society
Secretaries, Drs. L. L. Holst, A. W. Ssamygin and S. T. Konobejevsky. Meets monthly, first Monday, 8 P.M.

Scandinavian Roentgen Societies
The Scandinavian roentgen societies have formed a joint association called the Northern Association for Medical Radiology, meeting every second year in the different countries belonging to the Association.

BOOK REVIEW

Books sent for review are acknowledged under: Books Received. This must be regarded as a sufficient return for the courtesy of the sender. Selections will be made for review in the interest of our readers as space permits.

Dr. W. C. Röntgen. By Otto Glasser, Cleveland Clinic Foundation. Cloth. Price, $4.50. Pp. 169, with illustrations. Springfield, Illinois: Charles C Thomas, 1945.

In this issue of the American Journal of Roentgenology and Radium Therapy which commemorates the Fiftieth Anniversary of the discovery of the roentgen ray, it is particularly fitting that a review appear of this recently published book. As Dr. Glasser states in the preface, "The enthusiam that hailed the use of roentgen rays from the publication of Röntgen's first communication has never abated." Thus, as all radiologists join in paying honor to Röntgen, the book has been sponsored by the three leading radiological societies in the United States, the American Roentgen Ray Society, the Radiological Society of North America and the American College of Radiology.

Dr. Glasser among his many other activities has done an enormous amount of research on the life and work of Röntgen and he is without doubt the outstanding authority on the discoverer of the roentgen ray. In his previous book "Wilhelm Conrad Röntgen and the History of the Roentgen Rays" and in the chapter on "Wilhelm Conrad Röntgen and the Discovery of the Roentgen Rays" published in The Science of Radiology, Dr. Glasser has given many of the details connected with Röntgen's life and the facts leading up to the discovery of the rays as well as the event itself.

Since the year 1945 is the one hundredth anniversary of Röntgen's birth—he was born on March 27, 1845—as well as the fiftieth anniversary of the discovery of the roentgen ray, it seemed an opportune time to publish this additional small volume. It includes some of the material which Dr. Glasser has already published but it also contains new material unearthed by the author in his constant research on his favorite subject. It gives in a compact form the story of Röntgen's life and a new translation of the three communications dealing with the discovery of the roentgen ray—"On a New Kind of Rays" (preliminary communication), December 28, 1895; "On a New Kind of Rays" (second communication), March 9, 1896, and "Further Observations on the Properties of X-Rays" (third communication), March 10, 1897.

There is also given a list of the scientific papers of Röntgen as well as a chronology of his life. The volume has been attractively printed and bound. It offers easy access to the main events of Röntgen's life and the discovery of the roentgen ray and is a book which every radiologist will wish to include in his library.

Ruth Bigelow

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ABSTRACTS OF ROENTGEN AND RADIUM LITERATURE

ROENTGEN DIAGNOSIS

NECK AND CHEST

SHAPIRO, M. J., and KEYS, ANCEL. The prognosis of untreated patent ductus arteriosus and the results of surgical intervention. *Am. J. M. Sc.*, August 1943, *206*, 174–183.

This study was made to learn what could be expected in regard to longevity and cause of death in untreated cases of patent ductus arteriosus and to examine the records of surgery to date. The authors found it necessary to review the entire medical literature and have analyzed all the cases of patent ductus arteriosus in adults from which postmortem examinations have been reported. Eighty per cent of such patients eventually succumb to their cardiac lesion. Those patients who were alive at seventeen years of age averaged thirty-five years of age at death. At least 40 per cent of these patients died of subacute bacterial endarteritis and most of the remainder died of congestive cardiac failure. Spontaneous rupture of the pulmonary artery or the ductus occurred in a few cases.

Through personal correspondence with individual surgeons and internists the authors found that 140 patients had been operated on by a total of 25 surgical teams. Of these cases 107 were uncomplicated while operation was performed on 33 patients in the presence of subacute bacterial endarteritis. In the 107 uninfected cases, 81 operations were completely successful. Of the 33 patients who were operated on in the presence of subacute bacterial endarteritis 20 resulted in apparent complete success, i.e., the blood cultures became sterile and the patient's general condition improved markedly. Errors in diagnosis were made in only 2 instances in the entire group of 140 patients.

The authors conclude that surgery is advisable in the great majority of patients with patent ductus arteriosus with, or without, subacute bacterial endarteritis. In the latter case surgery affords more than a forlorn hope. The uninfected patient cannot expect a normal life span without surgery and is likely to develop subacute bacterial endarteritis at any time in spite of present apparent well being.—*J. J. McCort.*

BRUMFIEL, DANIEL M. Cardiac symptoms in persons with distortion of the mediastinum due to pulmonary tuberculosis. *Am. Rev. Tuberc.*, March, 1943, *47*, 231–252.

This article is a sequel to one published by the author in 1933. It pertains to a study of 38 patients in whom distortion of mediastinal structures was found in conjunction with pulmonary tuberculosis, and cardiac symptoms. None of the group had organic cardiovascular disease.

This study supports the author's earlier contention and the observations of others that distortions of the mediastinal structures *per se* may give rise to cardiac symptoms. Reference is made to the studies of Beck which indicated that "direct traction in the long axis of the heart or simple lateral displacement produced no maleffects, but rotation of the organ on its vertical axis or angulation on the axis of its anchorage at once altered both rate and rhythm."

Such changes have been noted following pneumothorax.

Other studies have indicated that mere stimulation of the sympathetics may cause tachycardia and extrasystoles. The author emphasizes that marked displacement of the superior mediastinum should be particularly productive of this type of circumstance—alleviated by small doses of mild sedatives.

One of the cases manifested cardiac extrasystoles and congestive failure and roentgen evidence of displacement of the arch of the aorta to the left and downward—with inevitable stretching of the left recurrent laryngeal nerve. Besides considering deviations of the arch of the aorta, one should consider deviations of the pulmonary arteries and the veins. The venae cavae are especially susceptable to angulations and thereby, alterations of blood flow—leading to anoxemia and dyspnea and myocardial embarrassment.

These changes may lead to pulmonary hypertension and right heart failure.

Deformities of the thoracic cage may impose derangements of the thoracic viscera.

Electrocardiographic findings were not especially significant; they were noticeable in only 3 of 12 cases where there appeared to be rotation (these showed right axis deviation). One case showed prolongation of the P-R interval to 0.22 second.

Estimates of prognosis seemed to be unreliable. Treatment was considered in terms of prevention, nonsurgical and surgical. In cases of fibrosis, contraction, and cavities, early thoracoplasty was performed. The ultimate deviations of the viscera following pneumothorax were carefully watched with consideration of later requirements of thoracoplasty or phrenic nerve paralysis. Systematic deep breathing exercises were applied in some cases.—*A. A. de Lorimier.*

ABDOMEN

Freedman, Eugene, Glenn, Paul M., and Laipply, Thomas C. Chronic gastritis simulating gastric carcinoma. *Arch. Int. Med.*, Jan., 1943, *71*, 23–37.

Over a period of three years the authors have encountered 5 cases in which the roentgen and gastroscopic appearance of localized, chronic hypertrophic gastritis simulated carcinoma of the stomach. The difficulties in diagnosis presented by these cases was such that carcinoma could not be excluded before an exploratory laparotomy was done. In 3 of the cases the true nature of the lesion did not become apparent until histopathologic examination of the resected specimen was made.

While the roentgen appearance of generalized hypertrophic gastritis can often be recognized, the localized forms are frequently difficult to differentiate from carcinoma. Even gastroscopically the differentiation between a localized inflammatory infiltration and one which is neoplastic cannot always be made.

Chronic gastritis if localized is not necessarily limited to the pyloric portion of the stomach. One of the authors' cases demonstrates that it may be situated on the side of the greater curvature. In 2 other cases it involved only the cardiac portion of the stomach. In 3 of the cases there was rigidity of the wall with absence of peristaltic waves with marked deformity of the contour. In 1 case it caused pyloric obstruction. The authors state that if the wide and irregularly arranged linear or polypoid rugae are associated with defects of contour, the differentiation between gastritis and carcinoma may be extremely difficult, indeed impossible. In certain instances repeated examinations at short intervals may show some regression in the changes favoring gastritis. In order to avoid diagnostic errors a roentgenologist must be conscious of the thick wall and in certain instances should report the possibility of this less serious disease.

Chronic gastritis is of importance because of its possible relation to gastric carcinoma. Patients with this condition should be carefully followed up with repeated roentgen and gastroscopic examinations to discover, if possible, gastric carcinoma in its early stage and thus increase the percentage of surgical cures of carcinoma of the stomach.—*J. J. McCort.*

Kantor, John L. Roentgenology of the digestive tract in the tuberculous. *Am. Rev. Tuberc.*, May, 1943, *47*, 484–492.

Intrinsic tuberculous lesions of the esophagus are rare, though occasional instances of nonspecific ulceration were found, wherein the tuberculous etiology was identified at autopsy. Mediastinal adhesions due to tuberculosis may be responsible for dysphagia.

Likewise, tuberculous lesions of the stomach are rare. Good has reported an instance of 0.34 per cent among unselected autopsies at the Mayo Clinic. Kantor has identified only 2 such cases in the past twenty-five years. In none of these was the diagnosis accomplished before death.

When the lacteal drainage of the small intestine is damaged (as by a tuberculous involvement of the mesenteric lymphatics), fat absorption may be impaired and steatorrhea may result. The findings may be the same as where there is defective fat splitting; the same as in sprue, celiac disease, lymphosarcoma of the intestine or of the mesenteric lymphatics, etc. These conditions may be featured by the "moulage sign"—the appearance of an ironing out of the valvulae conniventes (of the loops of the jejunum and occasionally even in the duodenum). It may be necessary to study the passage of barium repeatedly over a period of three to nine hours after its ingestion in order to identify this feature. Viewings or roentgenography should be accomplished every fifteen minutes in the beginning of the study and

every one to two hours when the ilium is being traversed.

Tuberculous ulcers in the intestines are chiefly located in the ileocecal region—according to Matz: cecum 52 per cent, ilium 39 per cent, ascending colon 32 per cent, ileocecal valve 15 per cent, descending colon 11 per cent, jejunum 8 per cent, appendix 7 per cent, duodenum 6 per cent, rectum 4 per cent, and sigmoid 3 per cent. Tuberculosis of the peritoneum was found in 8.5 per cent.

The author bemoans the fact that proper diagnosis of tuberculous lesions in the upper portion of the tract is usually lacking, prior to death. He attributes this mainly to failure to consider the possibilities in the tuberculous patient. He emphasizes the importance of indirect signs—increased irritability, spasms, stasis, and increased transport beyond the site of a lesion. However, even with substantial evidence, he advises the roentgenologist to resort to the expression "probable tuberculosis," instead of attempting more precise diagnoses. Errors in positive diagnosis are too likely to cause lack of confidence in the roentgen procedure.

Some of the lesions may be manifested by ulcerations; others by deformity, narrowing and irregularity of the lumen (such as due to a tuberculoma).

The most important conditions from which intestinal tuberculosis should be distinguished are the unstable colon, idiopathic ulcerative colitis, cancer, and regional ileitis.—*A. A. de Lorimier.*

SKELETAL SYSTEM

YASKIN, JOSEPH C., and TORNAY, ANTHONY S. Protruded intervertebral disk and hypertrophied ligamentum flavum. Criteria for diagnosis and indications for operation. *Am. J. M. Sc.*, August, 1943, *206*, 227–233.

Fifty verified cases were studied each of which was personally examined by one of the authors and many by both. The important findings were as follows: The condition is considerably more common in the male than in the female and may occur at any age, but the average age is 39.6 years. In more than half of the cases there was a history of some trauma, as a rule slight. The average duration of symptoms was 4.3 years. Intermissions were observed in 32 cases (varying from days to many years). The initial symptom in the majority of cases was located in the back, usually in the middle and paravertebral portions of the back. The pain is usually deep, unaccompanied by nerve or superficial tenderness and always aggravated by one or more of the several factors such as bending, sneezing or coughing, lifting, etc. Of the 50 cases 42 had a major disability, i.e., were unable to pursue their work and required sedatives and some narcotics. As regards contrast media studies, both air and lipiodol were used. With a few rare exceptions the air myelogram is thought to be a reliable diagnostic procedure. Air studies are unsatisfactory in the examination of lesion between L5 and S1 and often in the cervical swelling of the spinal cord. Of the 42 lipiodol studies, 3 were negative; 2 of these were found to have discs at operation and 1 was negative at operation. Of the 9 air studies 2 had both oil and air (one negative on roentgen study had a disc at L4 and L5).

The analysis of the 50 cases indicates recovery in 36 cases, improvement in 6 cases and failure in 8 cases. These were operated on within the last three and one-half years and the end-result cannot be accurately estimated as yet. It is possible that some cases now apparently recovered may have to be otherwise classified in the future.

After considering the various factors the authors feel that no case in which the diagnosis is reasonably certain should be regarded as a desirable operative subject unless: (1) previous adequate orthopedic and other treatment was afforded for a reasonable time (three to six months) without appreciable improvement in the disability; (2) the existence of moderate to major disability is present; (3) frequently recurrent major disability or recurrent moderate disability for considerable periods is present.—*J. J. McCort.*

OPAZO, LUIS. Radiodiagnóstico de las afecciones de la columna vertebral. (Roentgen diagnosis of diseases of the spinal column.) *Radiología*, Sept.-Dec., 1943, *6*, 199–209.

In making a thorough examination of the spinal column it is necessary to make not only the routine anteroposterior and lateral views but also oblique views and sometimes to resort to stereoscopy and planigraphy and often to make myelograms with air, oxygen or lipiodol. As lesions visible roentgenologically do not appear until quite late in these diseases a careful study of the history and thorough clinical

examination must also be made.

Tuberculosis of the spine is very frequent; it begins in the vertebrae and extends secondarily to the intervertebral discs, resulting in typical Pott's disease, which is most frequent in the dorsolumbar column and next in the lumbar column alone. Bone abscesses develop, followed by nervous disturbances. The abscesses may become calcified.

Degenerative diseases of the spinal column may originate in the vertebrae or intervertebral discs. The former group may be traumatic in origin or may be due to senile decalcification of the column of an osteomalacic type, ending in fracture of the vertebra without any direct injury. Three cases of this type are described.

The degenerative diseases beginning in the intervertebral discs may lead to calcification of the disc which is shown on the lateral roentgenogram. But the most interesting of these diseases of the discs are those that lead to herniation of the nucleus pulposus; these are the only ones that can be treated surgically and they are also interesting clinically as they cause serious subjective symptoms due to compression of the intraspinal nerves.—*Audrey G. Morgan.*

Toledo Henderson, Anibal. Radio-diagnóstico de las hernias del núcleo pulposo. (Roentgen diagnosis of hernias of the nucleus pulposus.) *Radiología*, Sept.-Dec., 1943, *6*, 235–241.

The author makes a study of hernia of the nucleus pulposus into the spinal canal, a condition that is quite frequent but comparatively little known. It is caused by force acting on the spinal column when the patient is bending over. Eighty-eight per cent of the cases of hernia of the nucleus pulposus are seen in the intervertebral discs of the lumbar region, most of them in the last two lumbar vertebrae. The remaining 12 per cent are distributed almost equally between the cervical and dorsal columns. The majority of cases are in men and occur around the age of forty.

The predominant symptom is pain, due to pressure on the nerve roots at their origin. A very large percentage of sciaticas are caused by these hernias. Treatment is surgical.

Diagnosis can be made by myelography with Lafay's heavy lipiodol. The hernia can be localized accurately in this way. After the hernia has been localized by roentgenoscopy, roentgenograms should be made in the anteroposterior and lateral positions. Heavy lipiodol does not have any bad effects if given with the proper technique and removed quickly from the spinal canal. The technique of the examination is reported in detail and illustrative roentgenograms are given, together with the histories of a number of cases.—*Audrey G. Morgan.*

Weber, Harry M. The present status of contrast myelography. *Am. J. M. Sc.*, Nov., 1943, *206*, 687–694.

This article constitutes a review of the literature up to November, 1944. From this review the author draws the following conclusions: 1. A comp'etely satisfactory medium for contrast myelography has not yet been discovered. 2. Lipiodol yields very accurate results. It allows the examination of the entire canal. The roentgenoscopic examination can be repeated later if desired and it will not only localize the lesion but many times will suggest the type of lesion present. On the other hand, lipiodol may cause some irritation of the meninges, its removal is difficult, and the medicolegal aspect of its use must always be considered. 3. Air myelography has limited but definite value, mostly for the examination of the lumbar region to detect protruded intervertebral discs. 4. The clinical and neurological picture is most important in the diagnosis of protruded intervertebral discs. Contrast myelography has value only when the findings are compatible with the clinical and neurologic impression.

(At the time this paper was written pantopaque had just appeared on the market consequently there were no articles available for review concerning it. However, since this paper was published a number of reports have appeared in the medical literature attesting to the superiority of pantopaque over previously used media for contrast myelography.)—*J. J. McCort.*

Riera Bauza, Melchor. Estudio sobre algunas enfermedades no infecciosas de la columna vertebral. (Study of some non-infectious diseases of the spinal column.) *Radiología*, Sept.-Dec., 1943, *6*, 261–268.

In order to understand certain pathological roentgen images in the spinal column, it is necessary to know the normal pictures of its normal embryological and later development.

These are described and they, as well as the diseases discussed, illustrated with roentgenograms.

Schmorl's nodules, or hernia of the nucleus pulposus, are described. They are an important sign in Scheuermann's disease or juvenile kyphosis. They are often attributed to trauma but Schmorl thinks the daily demands on the spinal column are sufficient to produce them. This disease appears generally between the ages of eleven and seventeen, affects the dorsal region chiefly and causes fibrous rigidity of the affected segment.

The commonest of the degenerative diseases of the spinal column is deforming spondylarthrosis which is characterized by the presence of osteophytes, which may form bridges between the vertebrae. Arthrotic lesions are said to occur in 80 per cent of men and 60 per cent of women more than fifty years of age. The clinical importance of the disease is slight. It causes pain in only about 10 to 20 per cent of cases; limitation of movement was the most important symptom in half of 20 cases examined. As a rule it does not cause any nerve lesions.

Baastrup in 1938 described osteoarthrosis of the spinous processes as the cause of certain forms of lumbago; this is known as Baastrup's disease. Degeneration of the intervertebral discs may cause pain resembling that of lumbago or sciatica.

A brief discussion is given of spondylolysis, spondylolisthesis and osteoporosis of the vertebrae. Senile kyphosis is a result of generalized osteoporosis of the spinal column—*Audrey G. Morgan.*

DI RIENZO, S. La espondilitis brucelósica. (Spondylitis in Brucella infection.) *Radiología*, Sept.-Dec., 1943, *6*, 171–198.

Involvement of the spine is very frequent in Malta fever, or infection with *Brucella melitensis*. The figures given by different authors vary greatly—from 20 to 75 per cent—because it is only in recent years that it has been possible to detect the lesions in an early stage. The disease affects not only the bodies of the vertebrae but also the soft parts—cord, meninges, nerves, intervertebral discs and ligaments.

When the disease becomes localized in the spine it causes pain and contractures. The pain varies greatly in severity from a mere pin-prick to the most intense and agonizing pain. The intensity of the pain is not related to the degree of involvement of the vertebrae. Contracture also is variable but it occurs in the most affected segment of the spine. Sometimes it is so great as to cause rigidity of the trunk and prevent even the slightest degree of flexion, extension or rotation while sometimes it is limited to a single muscle group. The vertebral injury does not cause any marked rise of temperature.

The injury of the vertebrae may cause abscesses resembling those of Pott's disease, which may appear on the surface of the body at a distance from the spinal injury. There is no parallelism either between the appearance of abscesses and the severity of the spinal injury. The development of the abscesses may cause a peritoneal syndrome with paralysis of the intestine and retention of its contents, nausea and vomiting, rapid pulse, hypotension and fainting.

The diagnosis of spinal injury may be suggested by the clinical symptoms but can only be made definitely by roentgen examination. Before examining the lumbar column the intestinal contents must be rendered uniform by the evacuation of gas and fecal matter with a cathartic—not by enema—and stimulation of intestinal peristalsis. A correct diagnosis can only be made with a lateral view. Both right and left views should be made and when a series of roentgenograms is made they should be marked right or left. Generators of high efficiency and tubes with a minimum focal spot must be used. Tubes with a rotating anode are almost necessary. The lesions shown by roentgen examination may include osteoporosis, segmental or generalized, hyperostosis in the form of parrot beaks or bone bridges, caries of various degrees and localizations, deformities of the discs which may extend even to total disappearance, and abscesses of the vertebrae.

Prognosis is serious, not only on account of the spinal injury but of the general infection. The disease is an occupational one which may be contracted in handling hides, working in dairies, making cheese, etc. It must be differentiated from other forms of spondylitis which are not occupational and the medicolegal questions involved should be understood.—*Audrey G. Morgan.*

PURRIEL, PABLO, RISSO, R., and ESPASANDIN, J. Localización de la brucelosis en la columna vertebral. (Localization of brucellosis in the spinal column.) *Radiología*, Sept.-Dec., 1943, *6*, 243–260.

The authors made a study of brucellosis of the spinal column based on 35 cases. Their cases were all in men. In general the statistics show a proportion of 8 men to 1 woman. The condition is found most frequently in the dorsolumbar column and rarely in the cervical column. They think the localization is determined by the amount of bone marrow in the affected vertebrae. Formerly brucellosis of the spinal column was thought to be rare but this was because the lesions visible roentgenologically do not appear until the chronic stage of the disease. The authors' 35 cases constituted 62 per cent of the total number of cases of brucellosis examined; they made a systematic roentgen study of the spinal column in all cases of brucellosis seen. There were no abscesses of the vertebrae in their cases, probably due to the fact that they were caused by *B. abortus* rather than *B. melitensis*.

The clinical symptoms are pain and sweating in the acute stage and in the chronic stage increasing localization of the pain in a definite segment of the spinal column with limitation of movement of the column, especially flexion. The pain does not stop on rest, which is a differential point from Pott's disease. Contracture of the paravertebral muscles also takes place, which helps to bring about rigidity of the spine.

The roentgenogram shows areas of decalcification and areas of condensation in the vertebrae. The process begins in the lamina of the vertebrae and when they are eroded hernia of the nucleus pulposus may take place. The hyperostosis may lead to the formation of parrot beaks and bridges of bone between the vertebrae. Decalcification may lead to flattening and finally breaking down of the vertebrae. Many roentgenograms are given showing the various changes in form of the vertebrae caused by the disease. These are not specific, however, and may be caused by other inflammatory diseases of the spinal column. Diagnosis cannot be based on roentgen examination alone but must include a study of the patient's occupational history and of the clinical condition, particularly of a history of a characteristic brucellosis fever in the early stages. The specific biological reactions are important in diagnosis. Intradermal injection of a suspension of dead *Brucella* causes an intense general and local reaction.—*Audrey G. Morgan.*

Ottolenghi, Carlos E. Sobre el diagnóstico de las lesions vertebrales por la biopsia por aspiración. (Diagnosis of vertebral lesions by aspiration biopsy.) *Radiología*, Sept.-Dec., 1943, *6*, 288–291.

There are diseases of the spinal column in which diagnosis either by clinical or roentgen examination is difficult or impossible. As surgical biopsy of the vertebrae is not advisable the author recommends in such cases the use of aspiration for obtaining biopsy material. He has devised an instrument for puncture and aspiration. This instrument and the technique of its use are illustrated by photographs. The material obtained in the aspirating syringe is placed in physiological solution and subjected to histological and bacteriological examination. He has practiced aspiration biopsy in 60 cases without having seen any ill effects from it and the information obtained was extremely useful in diagnosis.—*Audrey G. Morgan.*

Corsellas, M. M. Tumores malignos primitivos del raquis. (Primary malignant tumors of the spinal column.) *Radiología*, Sept.-Dec., 1943, *6*, 279–287.

Primary tumors of bone are rarely localized in the vertebrae. Among the 263 cases of bone tumor studied by the authors only 7 were in the spinal column, or 2.65 per cent; 3 of these were osteogenic sarcoma, 2 Ewing's sarcoma and 1 a plasmocytoma.

The roentgen images of osteogenic sarcoma, Ewing's sarcoma, myeloma and chordoma are described and illustrated with roentgenograms and photomicrographs of the histopathological findings are given.

Osteogenic sarcoma may be osteolytic or osteoplastic. The intervertebral disc is generally not affected. Late in the disease the tumor may break down the vertebra and invade the surrounding tissues, giving pictures that resemble those of Pott's disease. Pathological fractures are frequently seen in the last stages of these tumors. Early diagnosis is difficult, however, and sometimes paraplegia or paresthesias develop before tumor is suspected and roentgen examination made. The indemnity of the intervertebral disc is a point of differentiation from Pott's disease and other forms of spondylitis, such as those of typhoid fever, Malta fever, staphylococcus spondylitis, etc.

A roentgen diagnosis can be made of malignant tumor of the spinal column but never of its nature. Microscopic diagnosis is often difficult also.—*Audrey G. Morgan.*

DAZA, FELIX. Radio-diagnóstico del cáncer de la columna vertebral. (Roentgen diagnosis of cancer of the spinal column.) *Radiología*, Sept.-Dec., 1943, *6*, 211–219.

The author discusses cancer of the spinal column based on cases seen at the Central Laboratory of Radiography of the Salvador Hospital in Santiago de Chile. Roentgenograms were made of the spinal column in 1,699 cases, 853 of which proved to be pathological. Among these 853 cases 42, or 4.9 per cent, were cancer of the spinal column. These cancers may be of the osteolytic, osteosclerotic or mixed types. The osteolytic types are characterized by destruction of bone. In the beginning, the shape and size of the vertebra are preserved but later it yields to pressure and breaks down. This process may be sudden or gradual. The osteosclerotic form, in which the bone is sclerotic and eburnated, is almost always secondary to cancer of the prostate. The vertebrae do not break down as the sclerosis gives increased resistance to pressure.

Primary cancer of the spinal column is extremely rare. In the author's material there were only 2 cases, both sarcomas. Metastatic cancers invade the spinal column by way of the blood. They are always secondary to carcinoma; sarcoma does not produce metastases in the spine.

The osteosclerotic form must be differentiated from Albers-Schönberg's disease, or osteosclerosis fragilis, in which the roentgen appearance is similar but which differs in extent and localization of the process. The osteolytic form must be differentiated from tuberculous spondylitis and fracture. In Pott's disease the affected vertebrae fuse completely and the interline disappears, while in cancer the outlines of the vertebrae can always be seen. The differentiation from fracture must be based on the history and clinical examination as differentiation is not always possible from the roentgenogram.

The article is freely illustrated with roentgenograms of the different types of tumors studied.—*Audrey G. Morgan.*

CAMINHA, NICOLA C. Estudo radiológico dos tumores, sem o emprego de meios de contraste. (Roentgen study of tumors without the use of contrast media.) *Radiología*, Sept.-Dec., 1943, *6*, 220–234.

The roentgen literature in general says that roentgenography of tumors of the spinal canal is negative. The author believes this is a mistake and these tumors often cause changes which are visible on roentgen examination without the use of contrast media. He gives a table from Elsberg's work showing the different histopathologic types of tumors found in the spinal canal and their localization in the different segments of the vertebral column. He briefly reviews the appearance and clinical signs of the chief types of tumor found in the spinal canal, the meningiomas, neurinomas, sarcomas, ependymomas, idiopathic cysts and lipomas.

A description is given of the roentgen changes that are seen in the bodies of the vertebrae, the spinous processes and pedicles. He then studies the Elsberg-Dyke "rachimetric curve." He describes the method of making it and the changes found in the curve in intraspinal tumors, syringomyelia and meningocele. He thinks it is of great diagnostic value and may sometimes even be used as a substitute for myelography.

The article is freely illustrated with roentgenograms and Elsberg-Dyke curves of cases.—*Audrey G. Morgan.*

CARO, DAVID L., and INGBER, EDMUNDO. Valor clínico de la exploración radiológica de la articulación sacro-ilíaca. (Clinical value of roentgen examination of the sacroiliac joint.) *Radiología*, Sept.-Dec., 1943, *6*, 269–278.

In order to make a complete and correct roentgen examination of the complicated sacroiliac region, the patient should be placed symmetrically with reference to the film and the tube focus; anteroposterior, posteroanterior and oblique projections with different degrees of rotation around 45° should be used. The central ray should be directed on the segment of the joint that is to be studied. Routine interpretation should be avoided and a very careful study made of each individual case.

The anatomy of the joint is described and diagrammatic sketches of its constituent parts given; also a diagrammatic drawing of the roentgen image of the joint.

The authors conclude from their experience that lesions of the sacroiliac joint precede inflammatory and degenerative lesions of the spinal column; that they are an early phase of the latter and the only stage that can really be cured, and therefore they deserve much more careful attention on the part of roentgenologists than has heretofore been given them.—*Audrey G. Morgan.*

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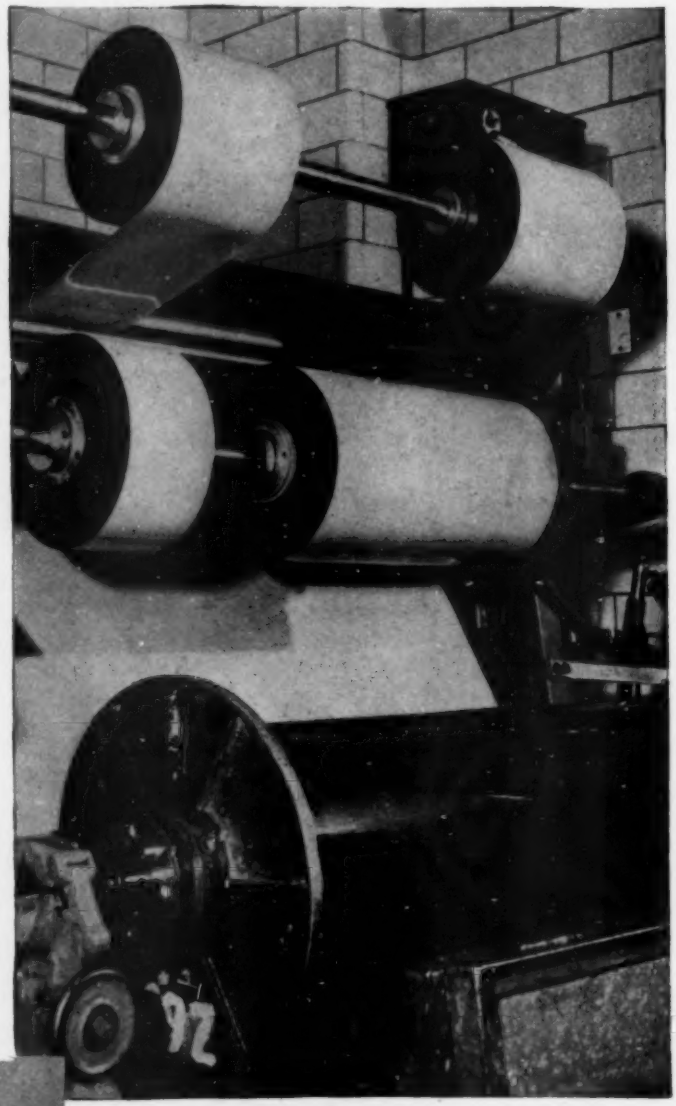

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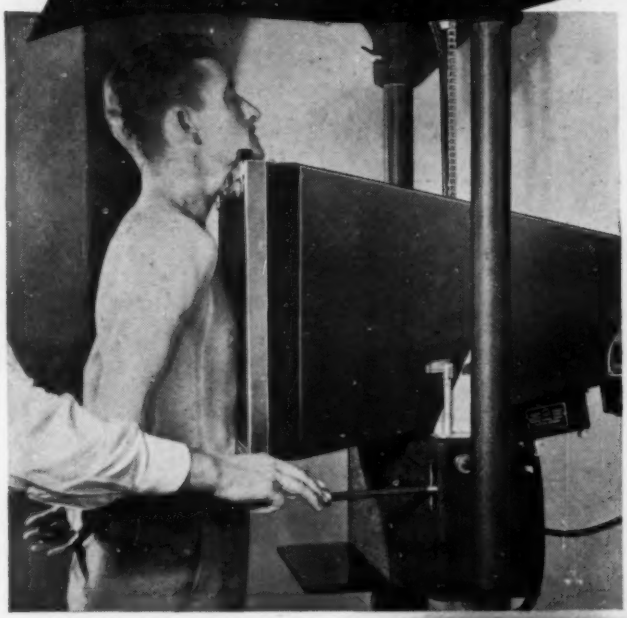

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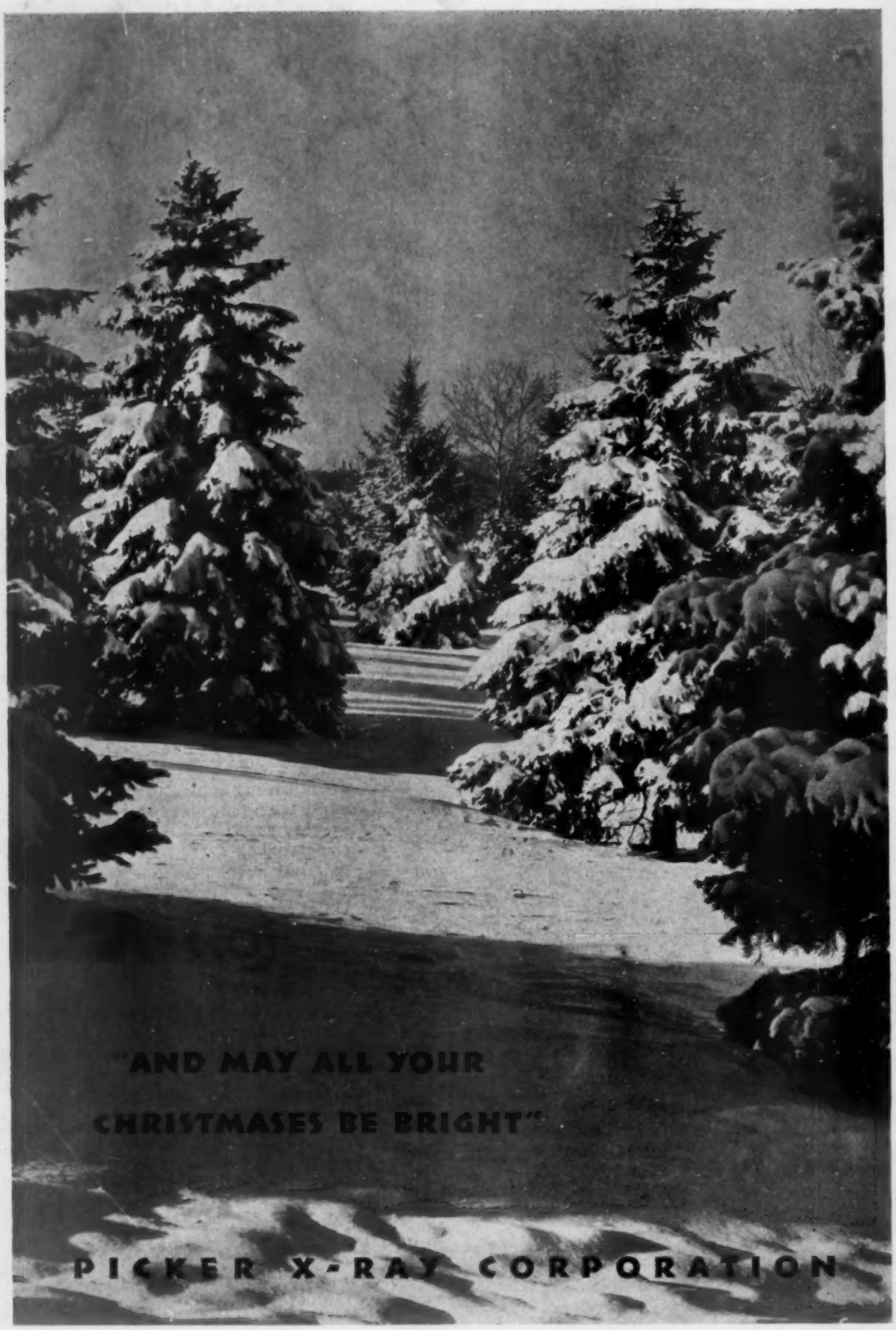
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